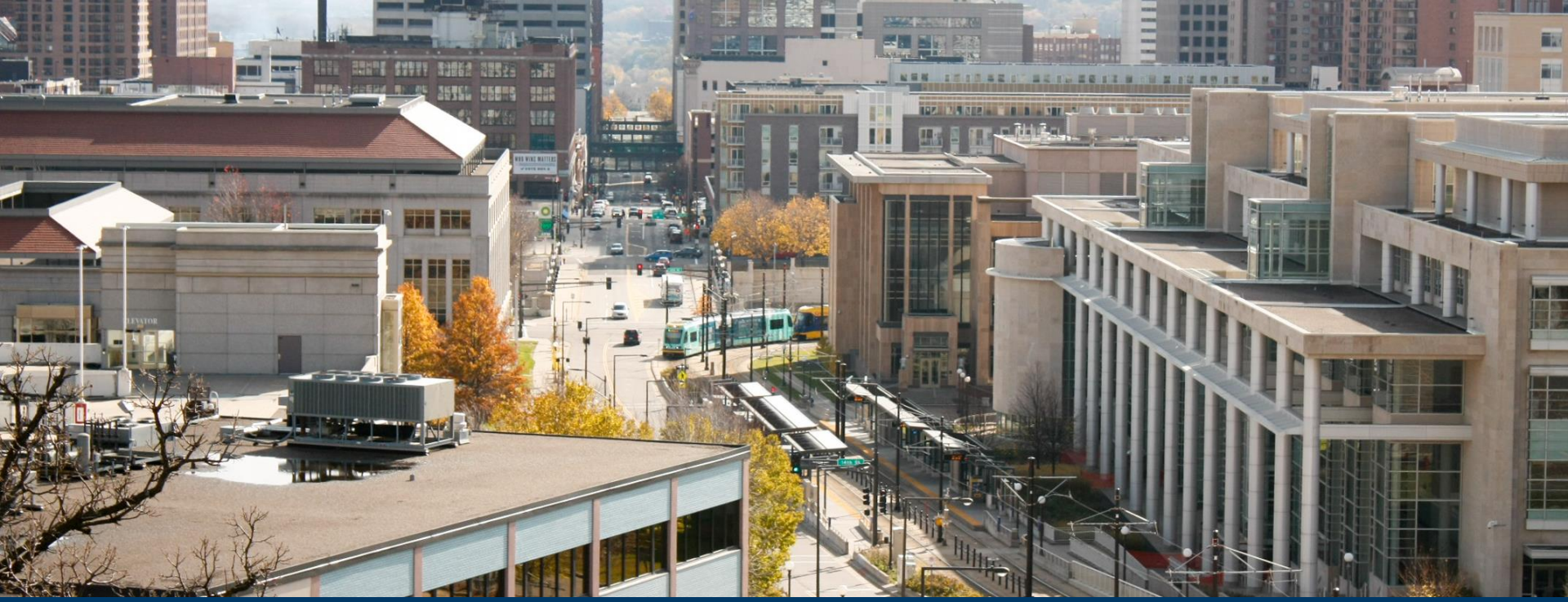


Pathways to Decarbonizing Transportation

A partnership with MnDOT, MPCA, MDA, EQB, Department of Commerce, and the McKnight Foundation

Tory Clark, Director, Energy + Environmental Economics

31 May 2019

DEPARTMENT OF TRANSPORTATION

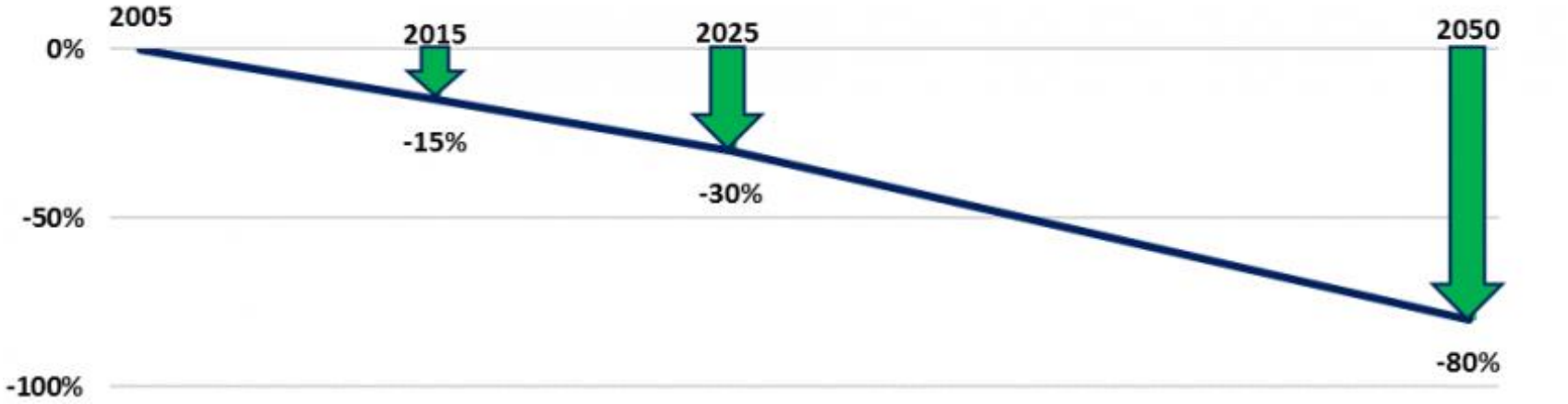
Agenda

- Background and Scope
- Modeling – Scenarios and Assumptions
- Modeling – Results
- Next Steps
- Questions
- Appendix

Background and Scope

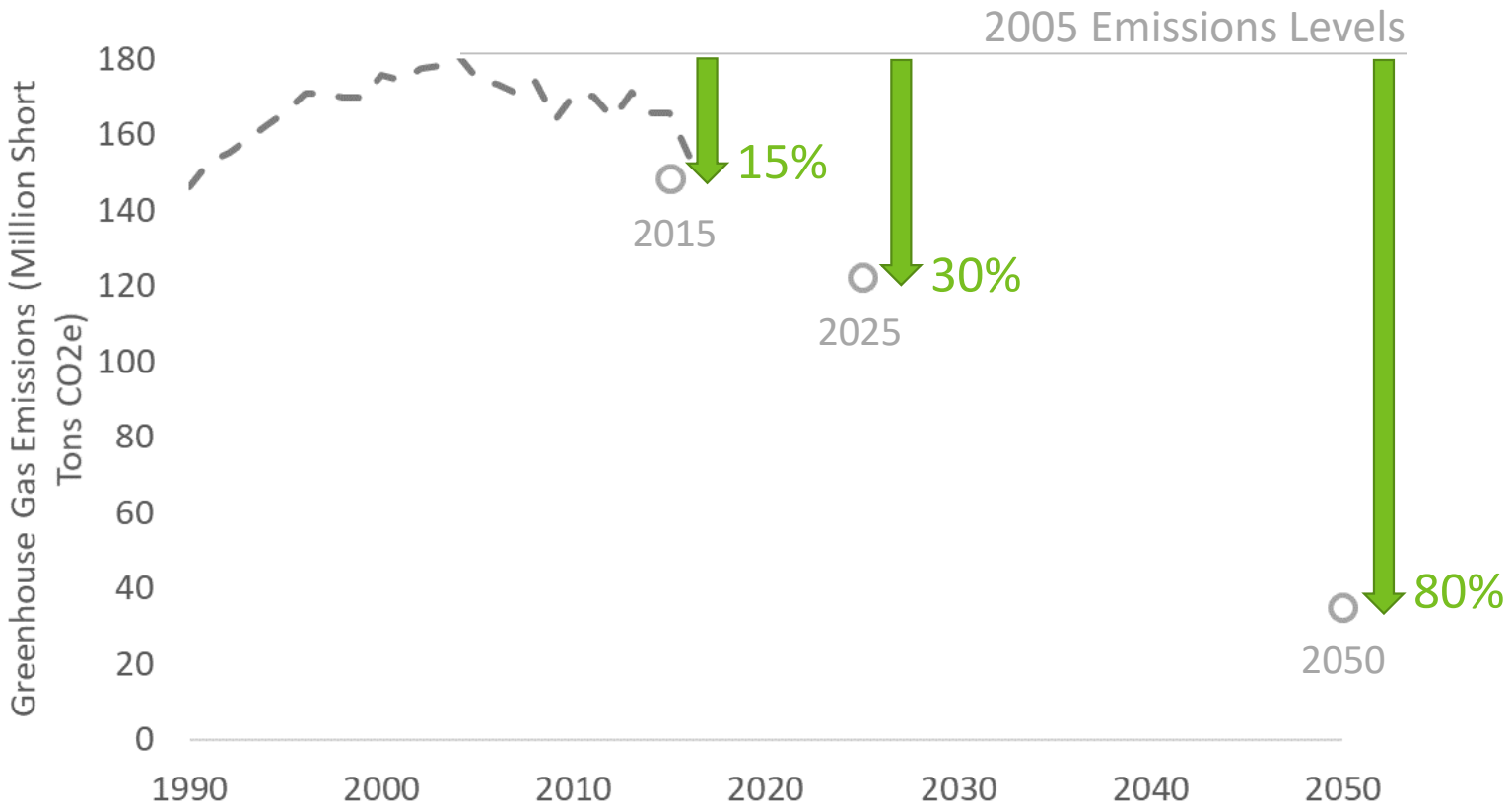
Next Generation Energy Act of 2007

The Next Generation Energy Act requires the state to reduce greenhouse gas emissions 80% by 2050, setting interim reduction targets in 2015 and 2025.



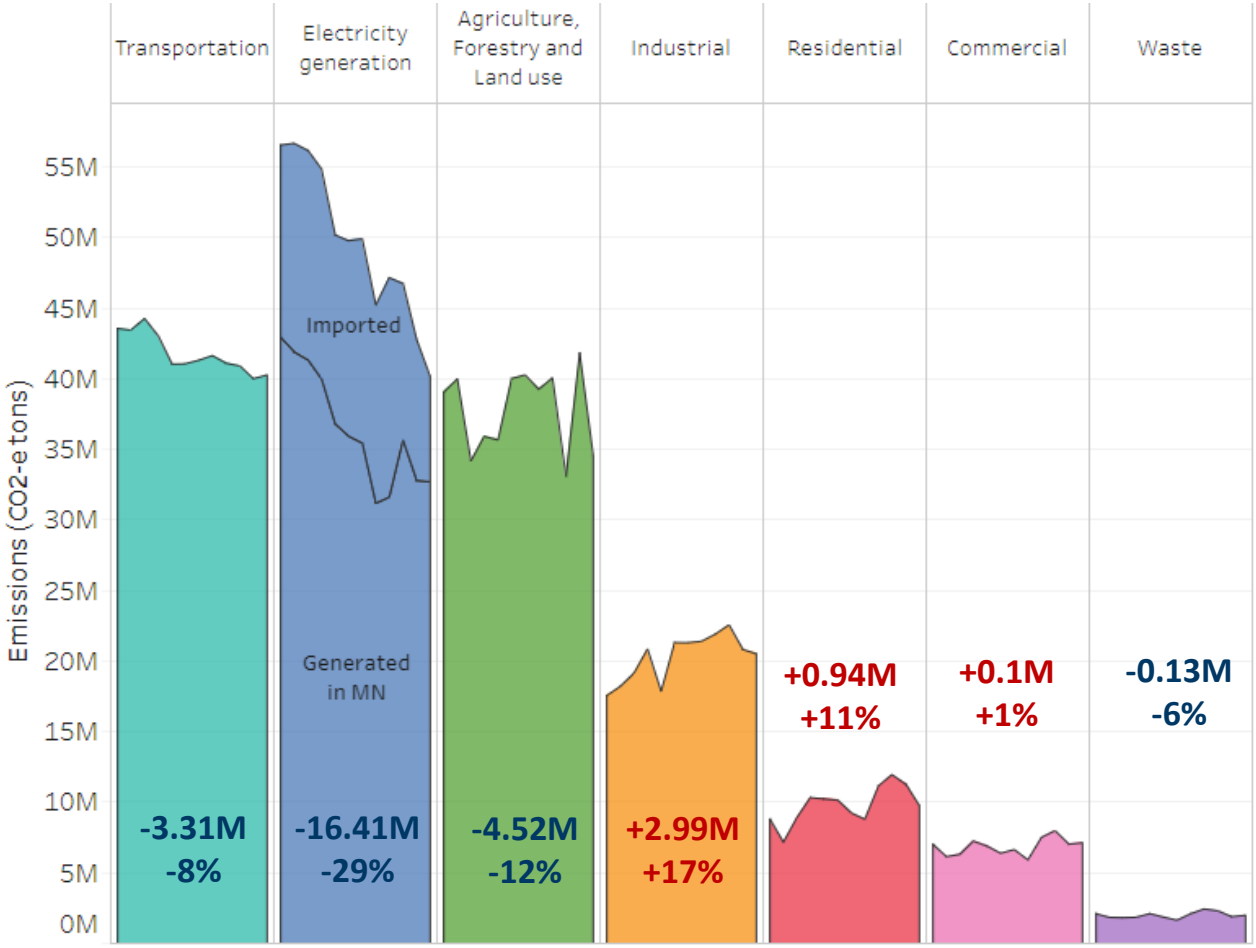
Progress Towards Next Generation Energy Act Goals

Historical Emissions in Minnesota and Next Generation Energy Act Goals



Changes in Emissions by Sector

Minnesota Emissions by Sector, 2005-2016



Source: Minnesota Pollution Control Agency, Greenhouse Gas Emission Inventory, 2005-2016

Minnesota Pathways to Transportation Decarbonization

Work with technical experts from the public, private, and nonprofits sectors to inform modeling assumptions and strategies that should be considered.

April – June 2019

Model different pathways for decarbonizing transportation.

April – May 2019

Meet with the public at locations around the state to hear their feedback and thoughts on strategies.

May – June 2019

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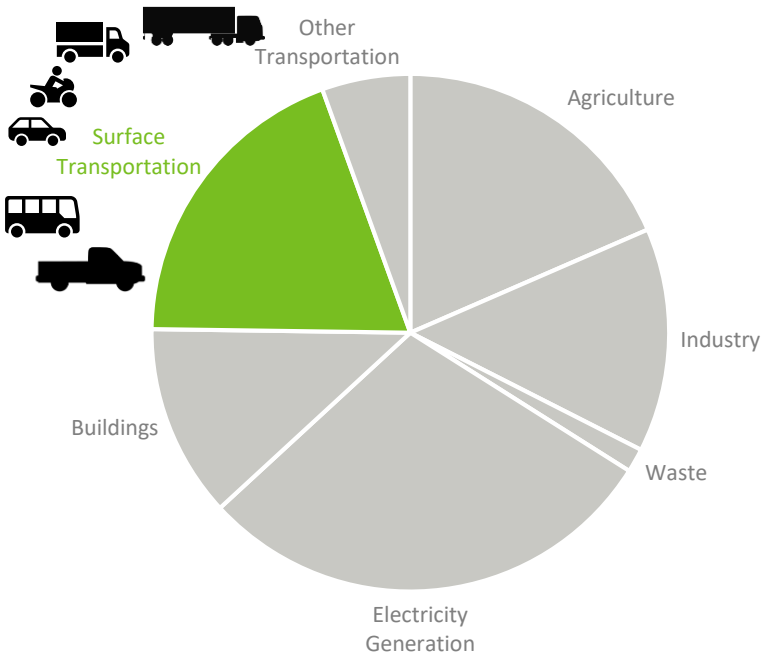
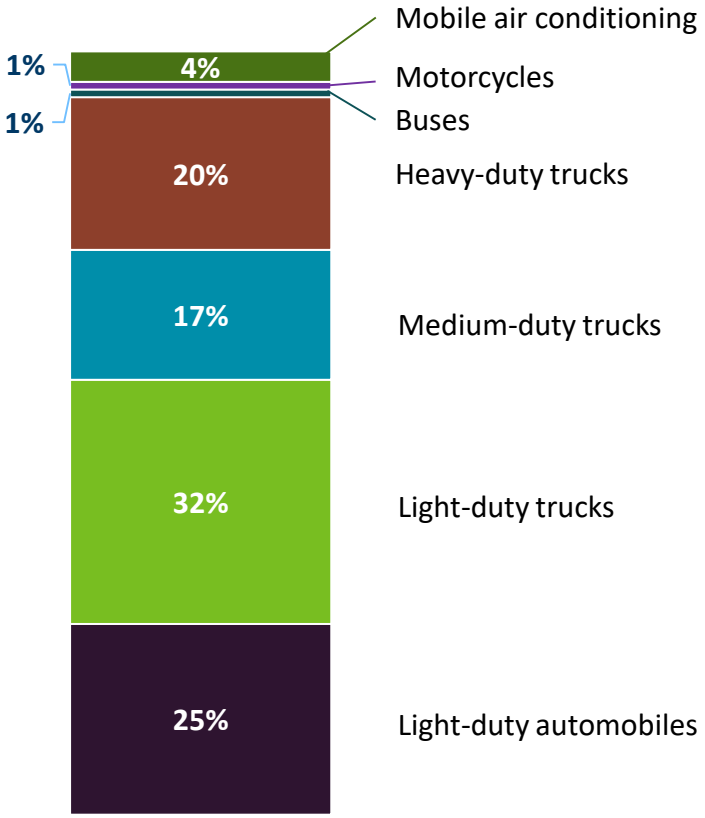
Focus of this Study

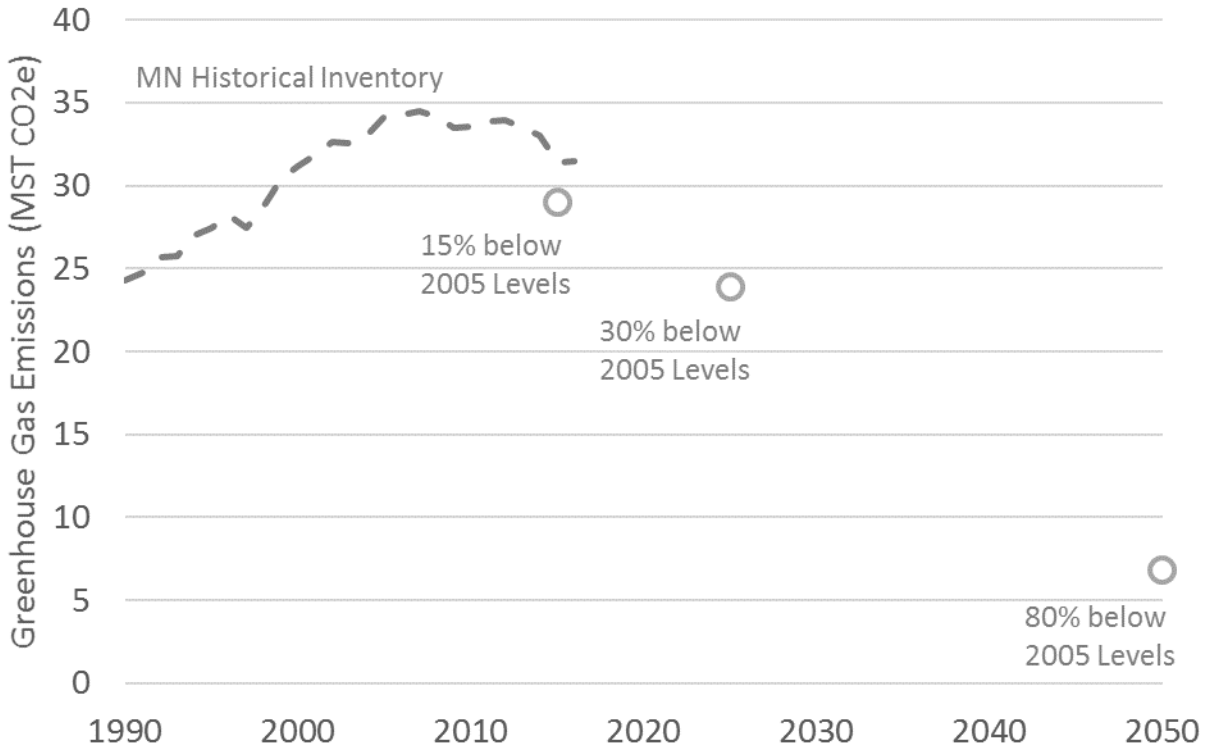
Minnesota Emissions Profile





Emissions from Surface Transportation in Minnesota

- Emissions from Surface Transportation were 8% below 2005 levels in 2016
- The goal of this analysis is to model measures and actions that could help Minnesota meet 2025 and 2050 Next Generation Energy Act goals for transportation



Why Model?

- Understand opportunities and challenges for reducing emissions from transportation in Minnesota
- Evaluate which actions achieve the most emissions reductions
- Understand timing of different actions (e.g. when do we need to start selling electric vehicles?)
- Capture interactions between measures and sectors
- Explore what combinations can help get us to our goals
- Provide a starting point for discussions about policies and incentives

Modeling - Scenarios and Assumptions

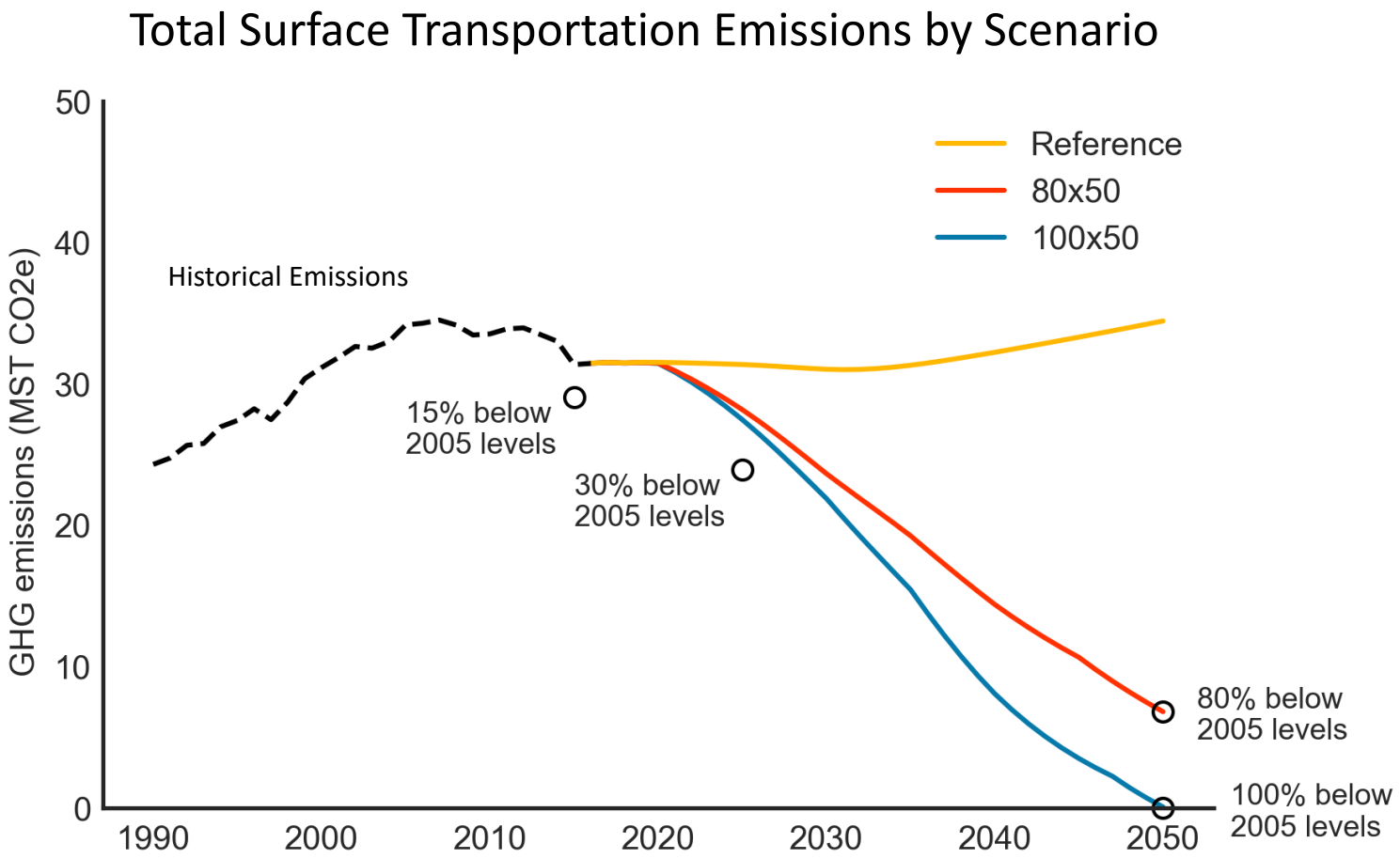
Scenario Definitions

- **Reference Scenario**
  - Business as usual scenario including current policies (e.g. expected adoption of electric vehicles)
- **80x50 Scenario**
  - One pathway that meets an 80% reduction in surface transportation greenhouse gas emissions by 2050 (using 2005 levels as a starting point)

  Not the only way to get to 80x50 and not a recommendation of what MN should do
- **100x50 Scenario**
  - One pathway that meets a 100% reduction in surface transportation greenhouse gas emissions by 2050 (using 2005 levels as a starting point)

  Not the only way to get to 100x50 and not a recommendation of what MN should do

Scenarios in Action



Note all results today focus on 80x50 scenario, more detail can be found in the appendix

Actions that can reduce emissions in transportation

Efficiency

- Improved fuel economy for new vehicles sold
- Increased sales of hybrid gasoline or diesel vehicles
- Reductions in urban vehicle-miles traveled

Electrification

- Increased sales of electric vehicles

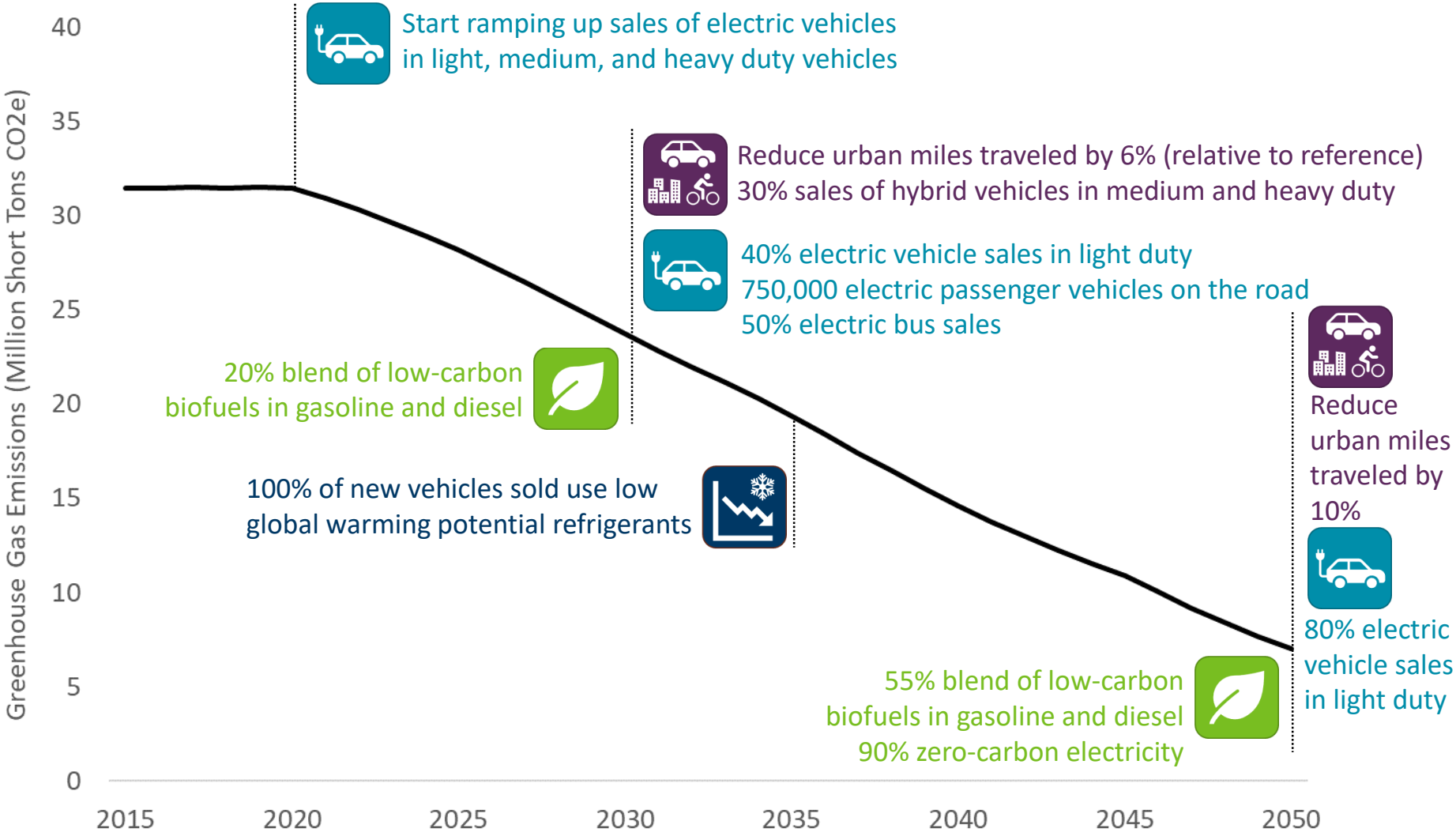
Non-energy sources

- Switch to vehicle refrigerants with lower climate impact

Low-carbon fuels

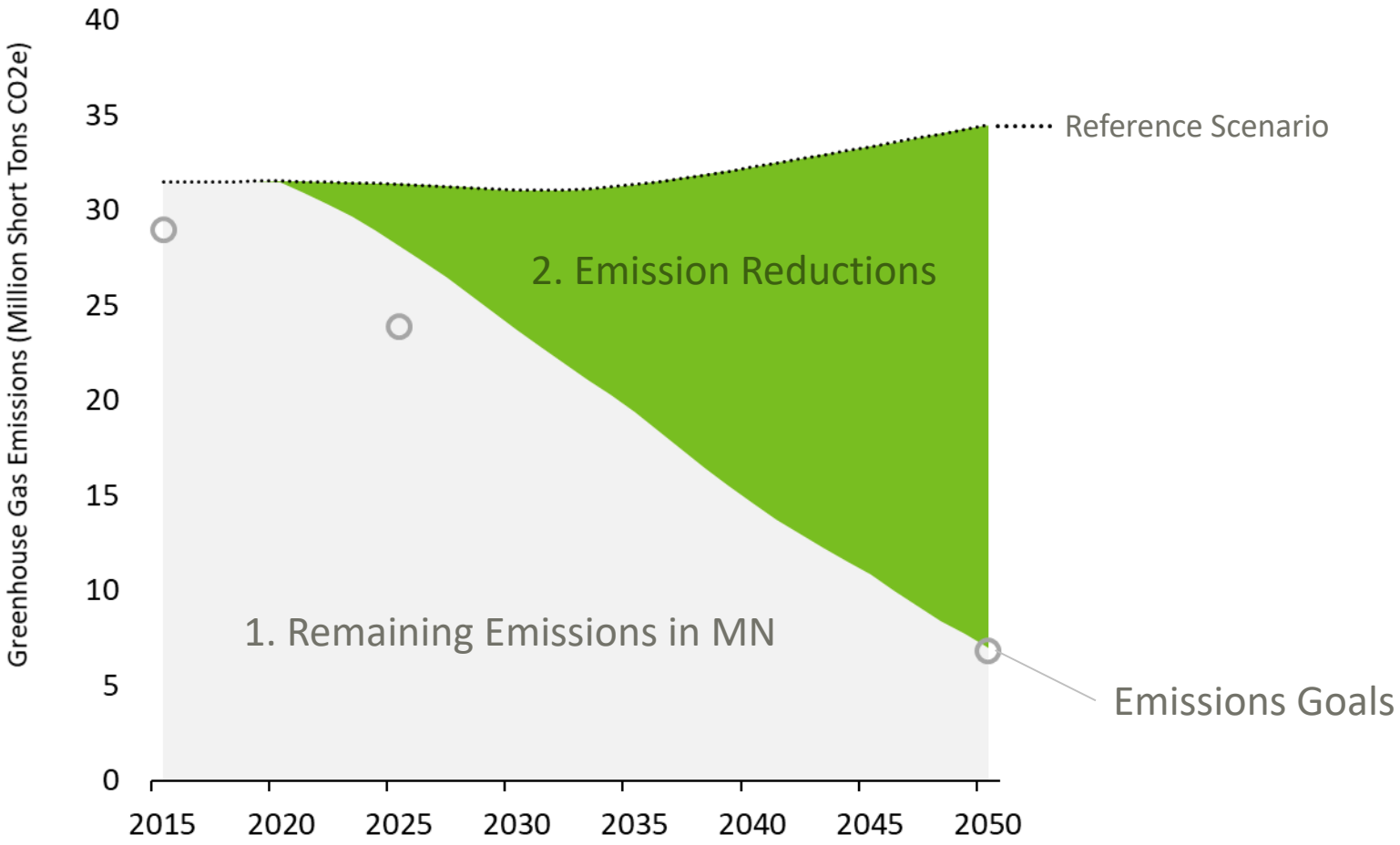
- Increase low-carbon biofuels
- Zero- or low-carbon electricity production

Minnesota Greenhouse Gas Emissions Reduction Measures in Transportation, 80x50 Scenario

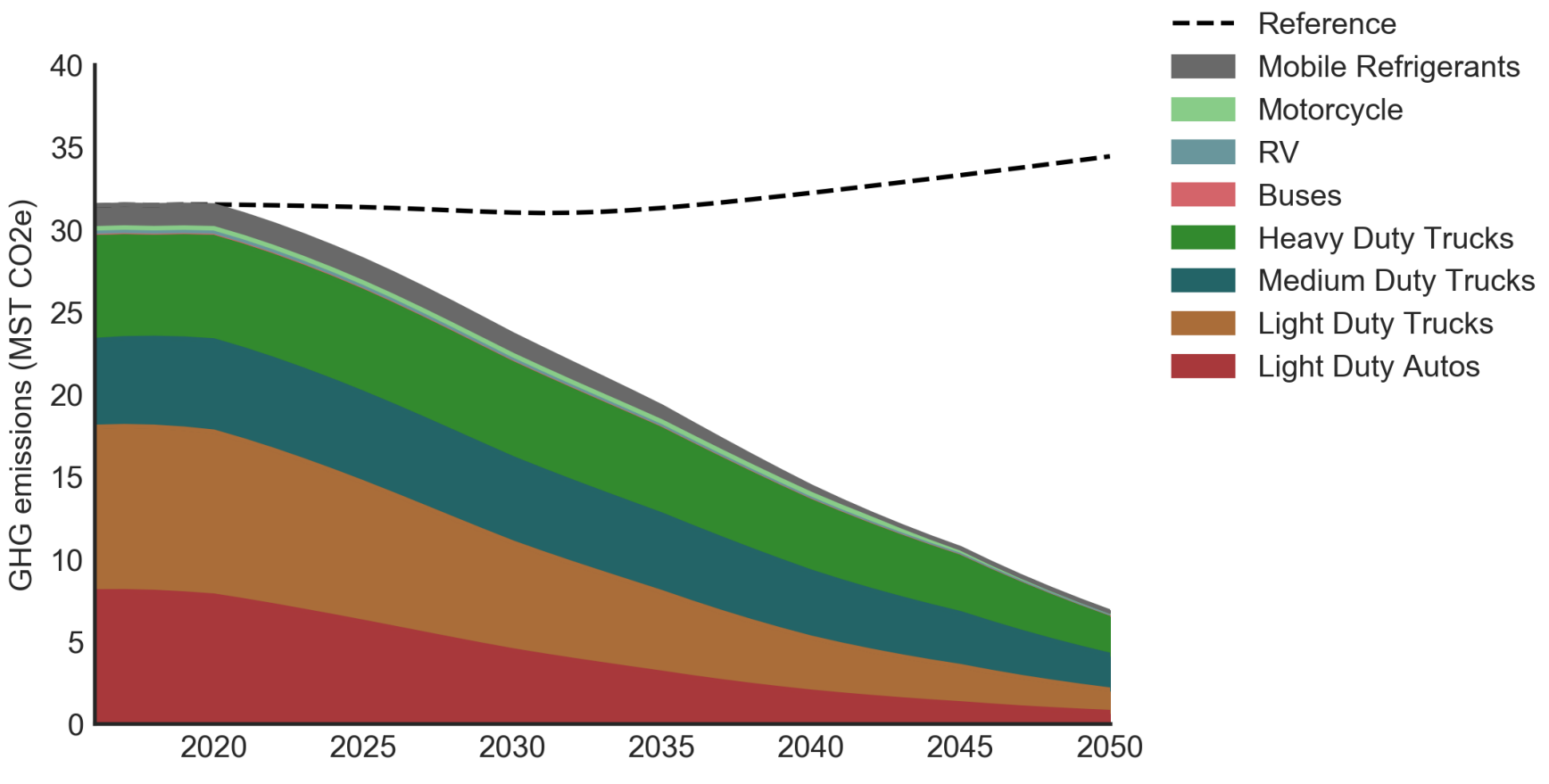


Modeling - Results

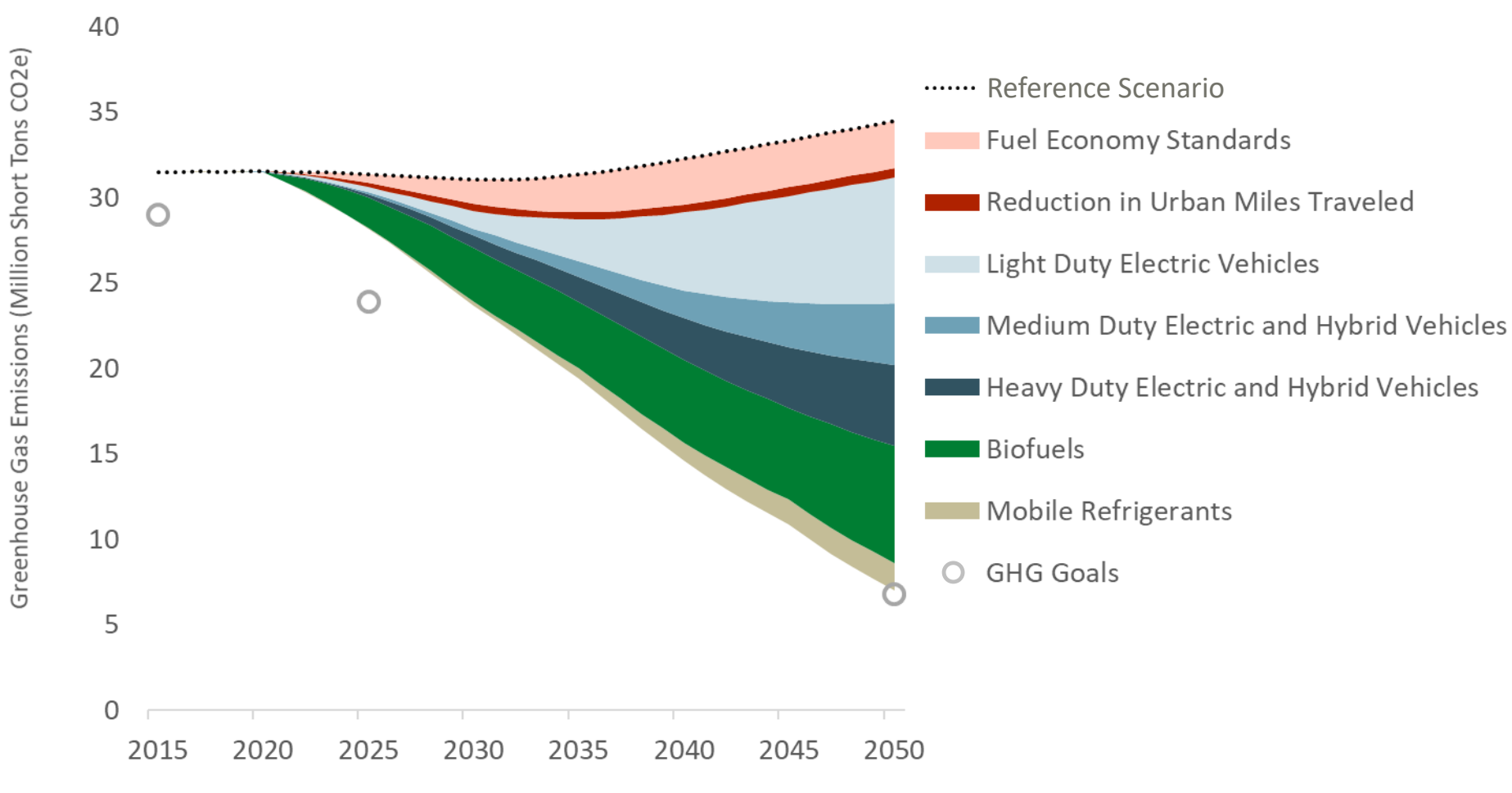
Two Ways to Think About Transformations



Remaining Emissions in Minnesota by Type
80x50 Scenario



Emissions Reductions by Measure
80x50 Scenario



From Modeling to Implementation

- Improved fuel economy can be incentivized through **federal or state efficiency standards**
- Reductions in urban vehicle-miles traveled can be achieved through **smart city design, bikeable and walkable neighborhoods, carpooling incentives, and improved public transit**
- Increased sales of electric vehicles can be incentivized through **consumer rebates, state vehicle targets, and improved public and workplace charging infrastructure**
- Reducing the carbon intensity of biofuels can be achieved through **improved agricultural and soil practices, process efficiency, and a low-carbon fuel standard**
- Increasing lower-carbon electricity can be achieved through **clean electricity standards, utility decarbonization targets, and coal retirements**

Next Steps

Survey

- MnDOT Pathways to Reducing Greenhouse Gas Emissions in Minnesota
- Open from **May 31 through June 19**
- https://mndotforms.formstack.com/forms/mndot_pathways_to_reducing_greenhouse_gas_emissions

Public Meetings

Twin Cities
- June 4th
- 6:00 pm - 8:00 pm
- Minneapolis Urban League

Bemidji
- June 5th
- 2:30 pm - 4:30 pm
- 6:00 pm - 8:00 pm
- Hobson Memorial Union, BSU

Duluth
- June 6th
- 2:30 pm - 4:30 pm
- 6:00 pm - 8:00 pm
- American Indian Community Housing Organization

Marshall
- June 11th
- 2:30 pm - 4:30 pm
- 6:00 pm - 8:00 pm
- Marshall Municipal Utilities

Rochester
- June 12th
- 2:30 - 4:30 pm
- 6:00-8:00 pm
- Mayo Civic Center

More information

http://www.dot.state.mn.us/us/sustainability/pathways.html

- Webinar recording
- Survey
- Public Meeting details and registration

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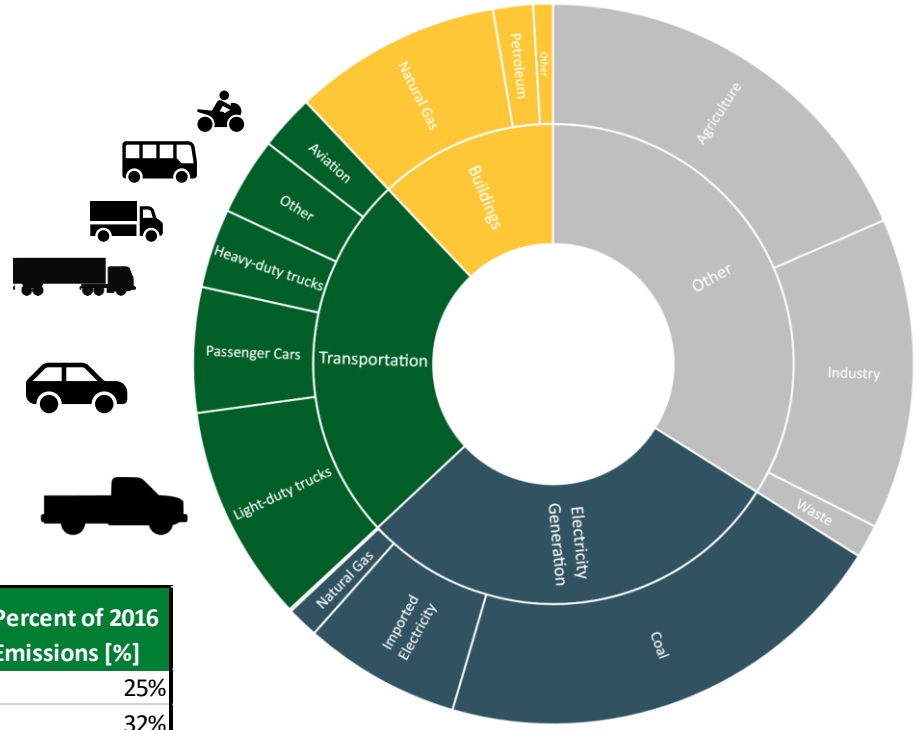
Questions?

Appendix

Modeling Scope

- Transportation emissions made up 26% of 2016 GHG emissions in Minnesota
- This project will focus on surface transportation, 20% of 2016 emissions
  - This excludes aviation, marine, rail, and military emissions

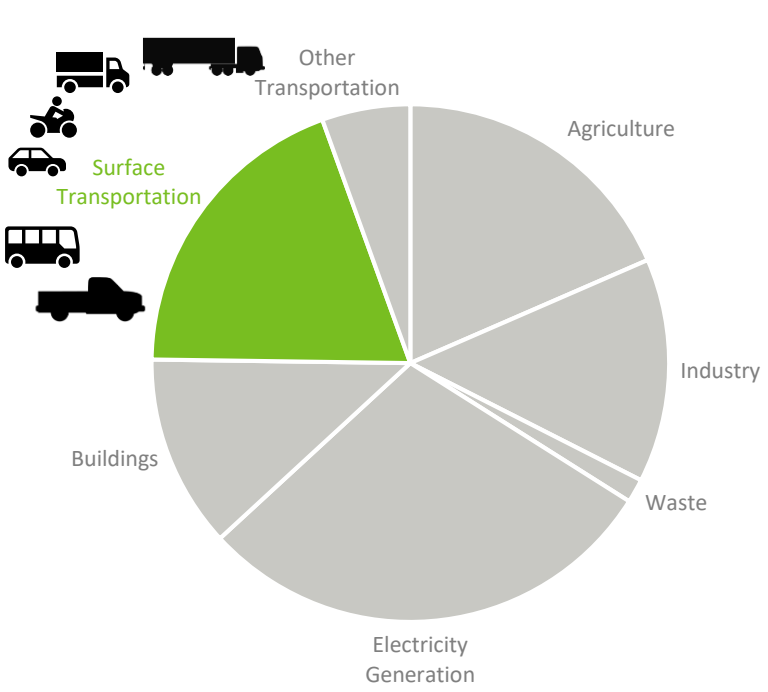
Minnesota GHG Emissions



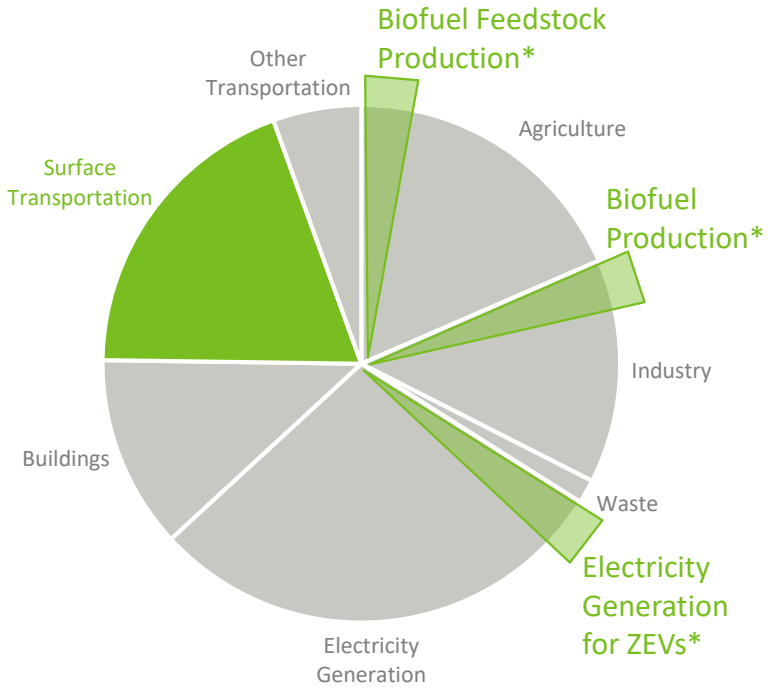
Sector	Subsector	Modeling Approach	Emissions in 2016 [MST CO2e]	Percent of 2016 Emissions [%]
Surface Transportation	Light Duty Autos	Stock Rollover	8.0	25%
	Light Duty Trucks	Stock Rollover	10.0	32%
	Medium Duty Trucks	Stock Rollover	5.3	17%
	Heavy Duty Trucks	Stock Rollover	6.2	20%
	Buses	Stock Rollover	0.3	1%
	RVs	Total Energy by Fuel	0.1	0%
	Motorcycles	Total Energy by Fuel	0.2	1%
	Mobile Air Conditioning	Total Emissions	1.4	4%
	All Sectors		31.5	100%

Modeling Scope

PCA Inventory Emissions ("PCA Accounting")



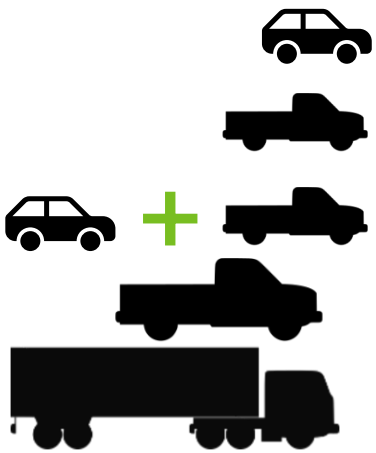
Upstream Emissions in MN ("Upstream Emissions")



*Size of upstream emissions are illustrative only

Abbreviation Key

Vehicle Types



LDA = light-duty automobiles (passenger cars)

LDT = light-duty trucks (e.g. smaller pickup trucks)

LDV = light-duty vehicles (LDAs + LDTs)

MDV = medium-duty vehicles (e.g. larger pickup trucks)

HDV = heavy-duty vehicles (e.g. semi-trailer trucks)

Other

BEV/EV = battery electric vehicle/electric vehicle

PHEV = plug-in hybrid electric vehicle

VMT = vehicle-miles traveled

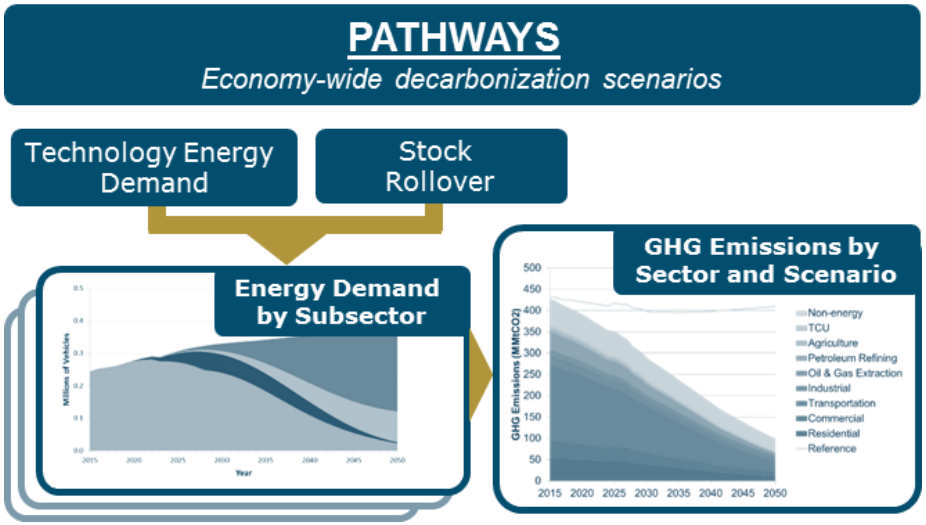
80x50 = 80% reductions in GHG emissions by 2050

100x50 = 100% reductions in GHG emissions by 2050

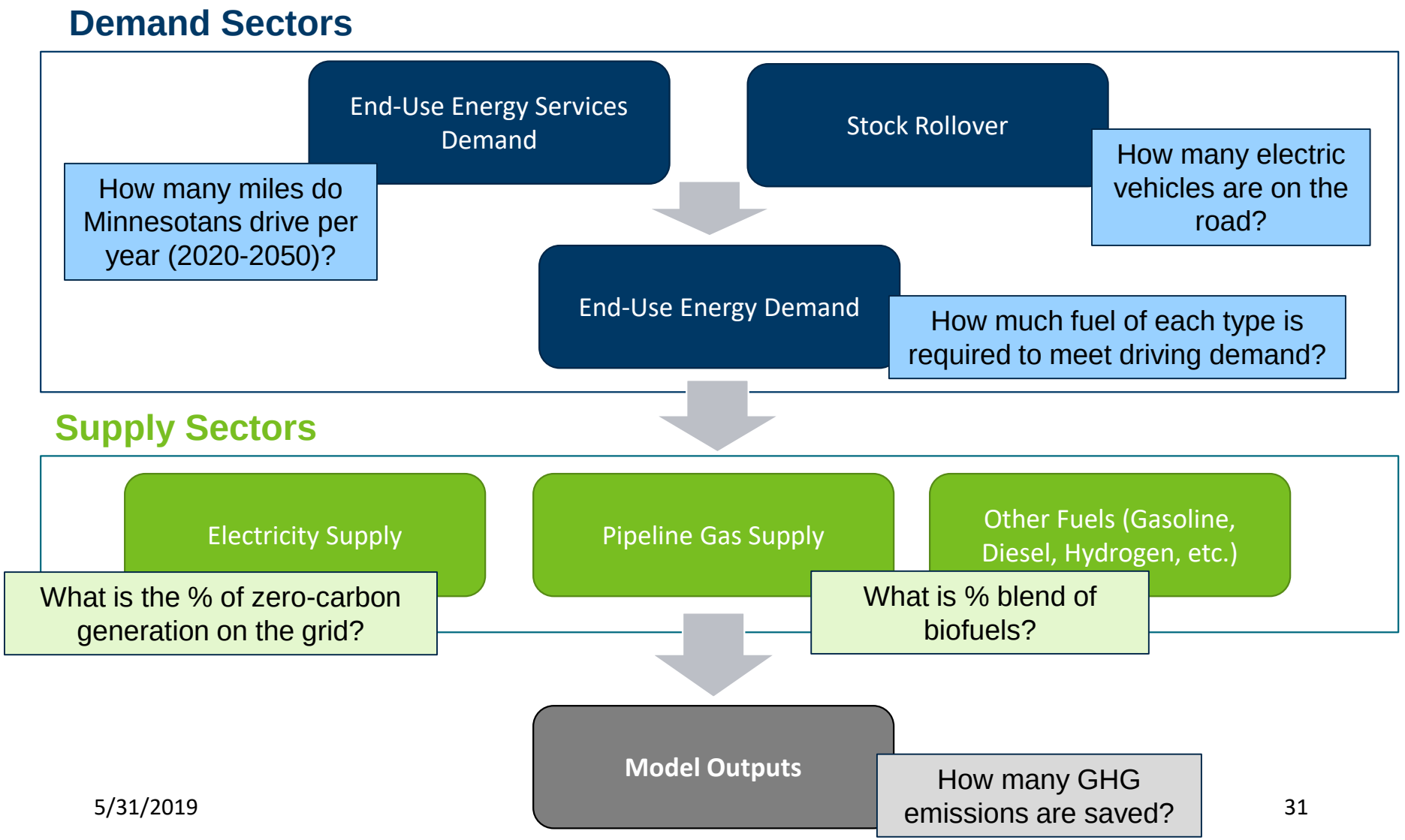
E3's PATHWAYS Model

- Economy-wide infrastructure-based GHG and energy analysis
  - Captures "infrastructure inertia" reflecting lifetimes and vintages of buildings, vehicles, equipment
  - Models physical energy flows within all sectors of the economy
  - Allows for rapid comparison between user-defined scenarios

- Scenarios test "what if" questions
  - Reference or counterfactual scenario for consistent comparison in future years
  - Multiple mitigation scenarios can be compared that each meet the same GHG emissions goal



PATHWAYS Modeling Framework



Categories of Model Outputs

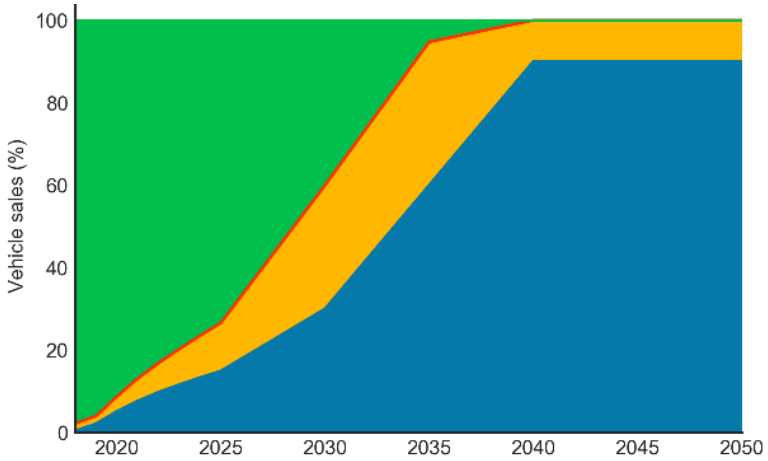
- Technology stocks & sales (e.g. Household appliances, Vehicles)
- Service demands and activity drivers (e.g. Vehicle miles traveled)
- Energy demand
- Energy supply (e.g. Electricity generation, Natural gas supply, Biofuel blends)
- Greenhouse gas emissions

All outputs are tracked by sector, fuel and year

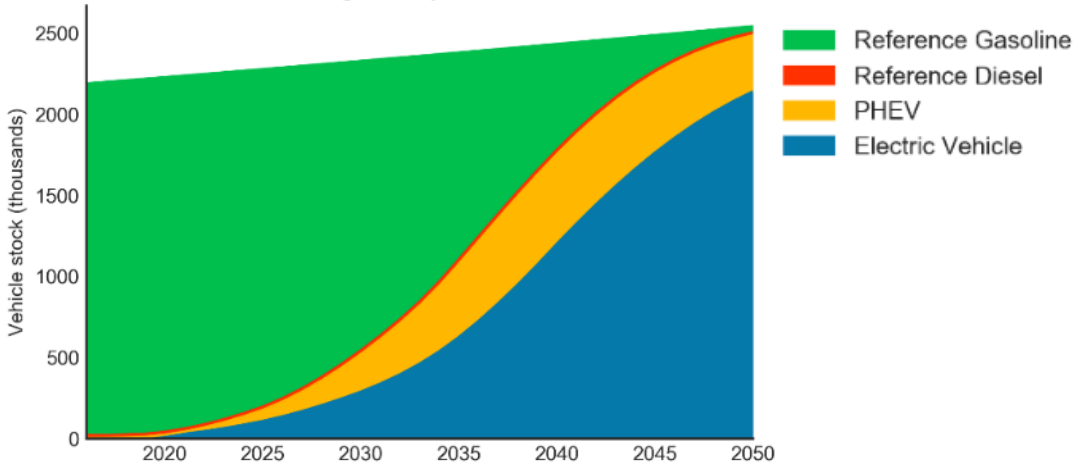
Example of Modeling Methodology
Stock Rollover for Zero-Emission Vehicles

- Light duty vehicles have an average life of ~15 years, which means they will need an average of 2 replacements over the next 30 years
  - Even if Minnesota reaches 100% of new sales as Zero Emission Vehicle alternatives, it will take significant time for existing gasoline vehicles to come off the road.
  - Delayed progress in sales could lead to costly programs to retire the existing fleet early (e.g. cash for clunkers programs).

% of New LDV Sales



Total Light Duty Vehicles



Key Scenario Assumptions by Scenario

	80x50 Scenario		100x50 Scenario	
Measure	2030	2050	2030	2050
Fuel Economy Standards	Included 2021-2026		Included 2021-2026	
LDV VMT Reductions	3% below Reference	5% below Reference	5% below Reference	10% below Reference
Light-duty vehicles	40% sales of EVs	80% sales of EVs	60% sales of EVs	100% sales of EVs (by 2040)
Medium-duty vehicles	30% sales of hybrids 10% sales of EVs	30% sales of hybrids 50% sales of EVs	30% sales of hybrids 20% sales of EVs	40% sales of hybrids 60% sales of EVs
Heavy-duty vehicles	30% sales of hybrids 10% sales of EVs 6.5% sales of CNG vehicles	30% sales of hybrids 50% sales of EVs 6.5% sales of CNG vehicles	30% sales of hybrids 20% sales of EVs 6.5% sales of CNG vehicles	33.5% sales of hybrids 60% sales of EVs 6.5% sales of CNG vehicles
Biofuels	20% blend ~40% reduction in CI relative to 2016	55% blend ~50% reduction in CI relative to 2016	20% blend ~50% reduction in CI relative to 2016	100% blend 100% reduction in CI relative to 2016
Electricity	22% reduction in carbon intensity relative to 2016	90% reduction in carbon intensity relative to 2016	22% reduction in carbon intensity relative to 2016	100% carbon-free
Mobile Refrigerants	100% sales by 2035		100% sales by 2025	

Key Drivers for Reference Scenario

Sector	Key Driver	Compound annual growth rate proposed for this study [%]	Data Source
Light-Duty Autos and Trucks	VMT	1% (2016-2025) 0.44% (2030-3050)	Projected growth through 2025, trending towards Population growth by 2030
Medium-Duty Vehicles	VMT	1.4%	EIA AEO 2019
Heavy-Duty Vehicles	VMT	1.4%	EIA AEO 2019
Buses	VMT	1.4%	EIA AEO 2019
RVs	Gasoline consumption	-0.9%	EIA AEO 2019
Motorcycles	Gasoline consumption	-0.9%	EIA AEO 2019

Reference Scenario Assumptions

Sector	Measure	Assumption
LDVs	Federal Fuel Economy Standards	Included through 2020, not extended 2021-2026
	LDV EV Sales	8.9% sales of EVs by 2030, 16% by 2050 (from EIA AEO)
	LDV VMT growth	1% growth 2016-2025, transitioning to 0.44% growth by 2030 (tracking with population)
MDVs	MDV EV + Hybrid Sales	N/A
	MDV VMT growth	1.4% 2016-2050
HDVs	HDV EV + Hybrid Sales	N/A
	HDV VMT growth	1.4% 2016-2050
Buses	Electric Buses	N/A
	Bus VMT growth	1.4% 2016-2050
Biofuels	Ethanol	7.4% average blend in 2016 (energy basis)
	Ethanol carbon intensity	Constant carbon intensity
	Biodiesel	20% biodiesel by 2018 (12.5% annual average)
	Biodiesel carbon intensity	Constant carbon intensity
Electricity	Electricity	48% zero-carbon generation statewide, 22% decrease in carbon intensity by 2025
RVs	Biofuels for RVs	N/A
Motorcycles	Electric Motorcycles	N/A
Mobile Refrigerants	Lower GWP Refrigerants	N/A

80x50 Scenario Assumptions

Sector	Measure	Assumption
LDVs	Federal Fuel Economy Standards	Extended through 2026
	LDV EV Sales	40% sales by 2030, 80% by 2050
	LDV VMT growth	3% reduction relative to reference (for whole state) by 2030, 5% by 2050
MDVs	MDV EV + Hybrid Sales	40% sales by 2030, 80% by 2050
	MDV VMT growth	1.4% 2016-2050
HDVs	HDV EV + Hybrid Sales	40% sales by 2030, 80% by 2050
	HDV CNG Vehicle Sales	6.5% sales by 2030
	HDV VMT growth	1.4% 2016-2050
Buses	Electric Buses	50% sales by 2030 (of those 100% BEV)
	CNG Buses	7.5% sales by 2030
	Bus VMT growth	1.4% 2016-2050
Biofuels	Ethanol	20% blend by 2030, 55% by 2050
	Ethanol carbon intensity	Declining carbon intensity (58% improvement by 2030, holding constant thereafter)
	Biodiesel	20% blend by 2030, 55% by 2050
	Biodiesel Carbon Intensity	Declining carbon intensity (25% improvement by 2030, 50% improvement by 2050)
Electricity	Electricity	90% zero-carbon generation statewide by 2050
RVs	Biofuels for RVs	20% blend by 2030, 55% by 2050
Motorcycles	Electric Motorcycles	50% of motorcycles are electric by 2050
Mobile Refrigerants	Lower GWP Refrigerants	All vehicles sold by 2035 have low-GWP refrigerant

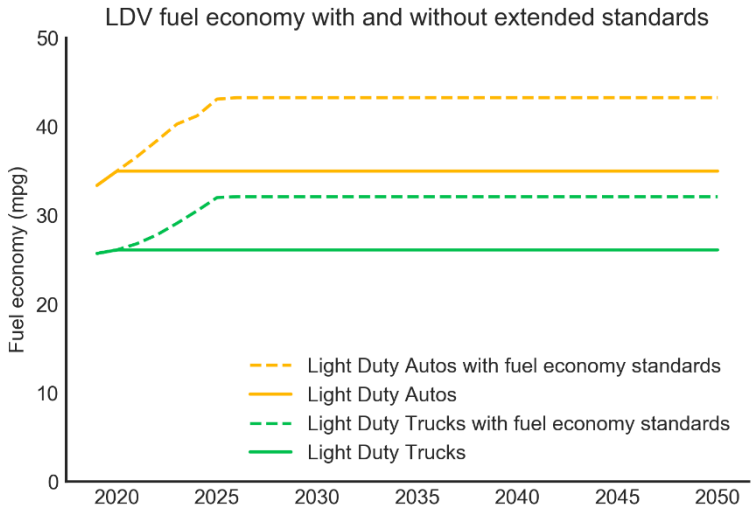
100x50 Scenario Assumptions

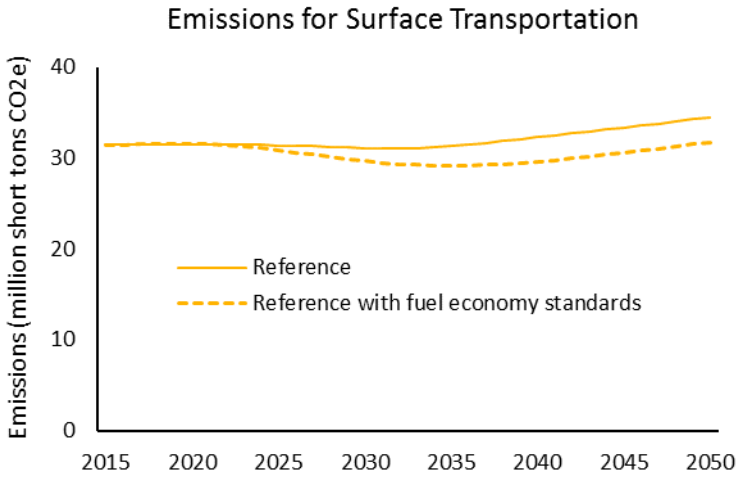
Sector	Measure	Assumption
LDVs	Federal Fuel Economy Standards	Extended through 2026
	LDV EV Sales	60% by 2030, 100% by 2040
	LDV VMT growth	5% reduction relative to reference (for whole state) by 2030, 10% by 2050
MDVs	MDV EV + Hybrid Sales	50% sales by 2030, 100% by 2050
	MDV VMT growth	1.4% 2016-2050
HDVs	HDV EV + Hybrid Sales	50% sales by 2030, 100% by 2050
	HDV CNG Vehicle Sales	6.5% sales by 2030
	HDV VMT growth	1.4% 2016-2050
Buses	Electric Buses	50% sales by 2030 (of those 100% BEV)
	CNG Buses	7.5% sales by 2030
	Bus VMT growth	1.4% 2016-2050
Biofuels	Ethanol	20% blend by 2030, 100% by 2050
	Ethanol carbon intensity	Declining carbon intensity to carbon-neutral fuels by 2050
	Biodiesel	20% blend by 2030, 100% by 2050
	Biodiesel Carbon Intensity	Declining carbon intensity to carbon-neutral fuels by 2050
Electricity	Electricity	100% zero-carbon generation statewide (emission factor goes to zero by 2050)
RVs	Biofuels for RVs	20% blend by 2030, 100% by 2050
Motorcycles	Electric Motorcycles	100% of motorcycles are electric by 2050
Mobile Refrigerants	Lower GWP Refrigerants	All vehicles sold by 2025 have low-GWP refrigerant

Vehicle Fuel Economy

- Fuel economy standards for light-duty vehicles has a significant impact on the energy consumption and emissions from internal combustion engine vehicles

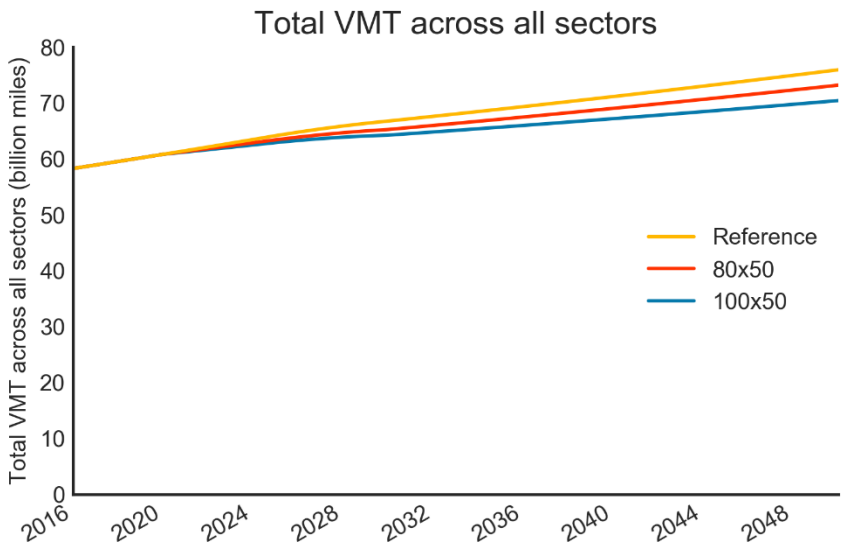
- Reference Scenario
  - Include improved vehicle fuel economy through 2020
- 80x50 and 100x50
  - Include extended improvements through 2026





Changes in Urban Vehicle-Miles Traveled

- There are many ways to reduce urban or metro vehicle-miles traveled (VMT)* including improved public transit, smart city design, carpooling, walking or biking
- Reference
  - Near-term growth (1%) through 2025, transitioning to population growth rate by 2030 (0.44%)
- 80x50 Scenario
  - Reductions of 6% by 2030 and 10% by 2050 (in light-duty vehicles only)
- 100x50 Scenario
  - Reductions of 10% by 2030 and 20% by 2050 (in light-duty vehicles only)

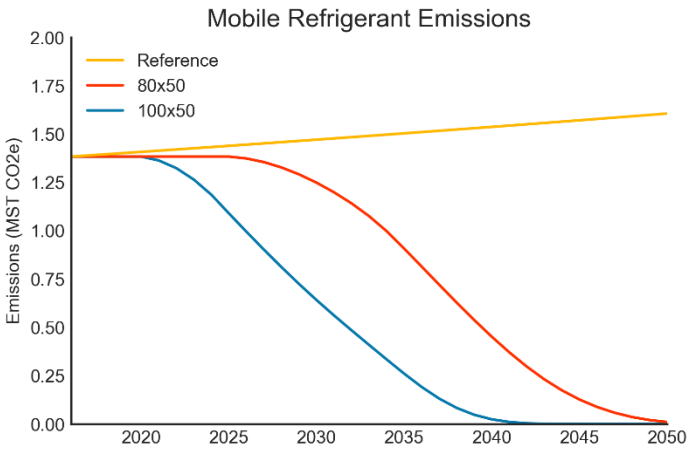


VMT reductions in urban areas can provide significant co-benefits for cities. This analysis only captures direct changes in energy consumption, GHG emissions, and statewide air pollutants.

*Urban and metro VMT was assumed to be 49% of total statewide VMT. No VMT reductions were assumed outside urban areas.

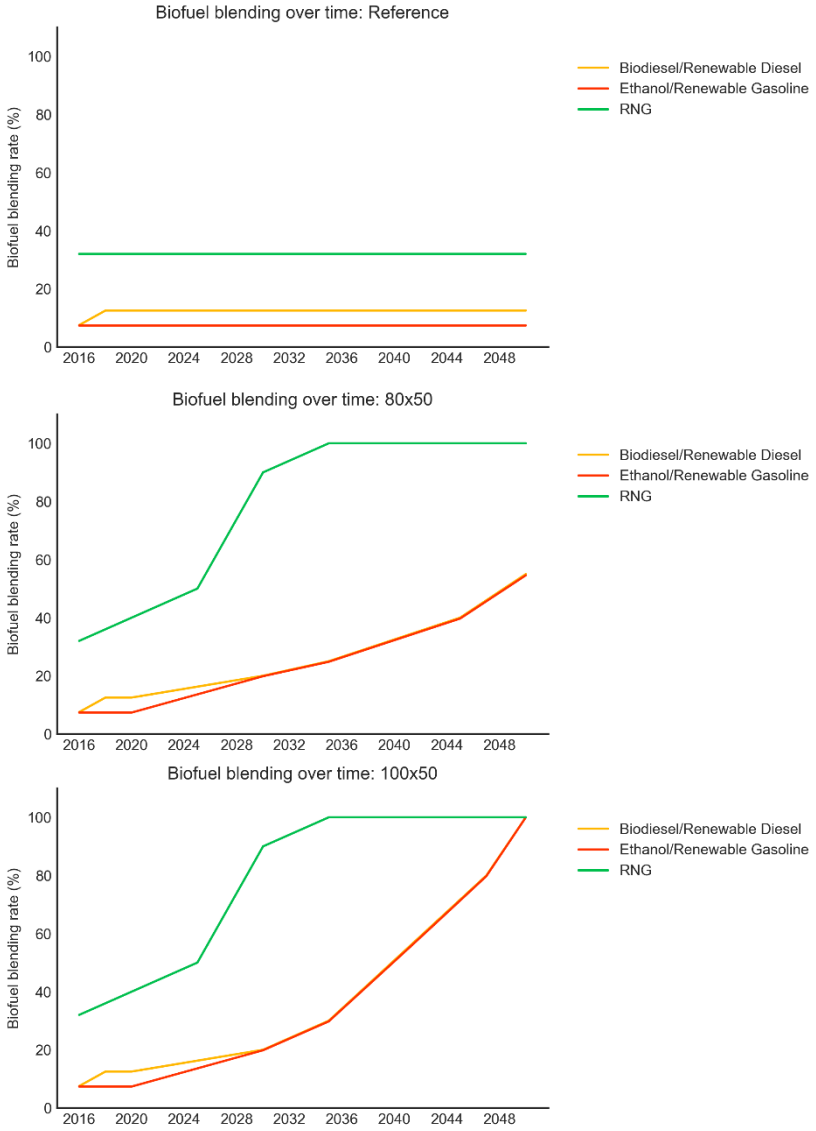
Mobile refrigerants

- Existing refrigerants in vehicles have a very high global warming potential (GWP). We assume that new vehicles can switch to a low-GWP refrigerant (e.g. CO2). Successful action in MN will depend on other states (e.g. CA) and US EPA.
- Reference
  - Grows with total number of vehicles (0.44% per year)
- 80x50 Scenario
  - All new cars sold by 2035 use low GWP refrigerant
- 100x50 Scenario
  - All new cars sold by 2025 use low GWP refrigerant



Low-carbon fuels: Biofuels
Blending rates over time

- We assume that biofuel blend rates hold constant in the Reference scenario, and slowly ramp up over time in the 80x50 and 100x50 scenarios
- Biofuels are treated as technology-agnostic, to leave room for either conventional or advanced biofuels to meet MN's need for low-carbon fuels
- If conventional biofuels are blended at rates beyond ~20%, fueling infrastructure and vehicle fleet factors will need to be addressed

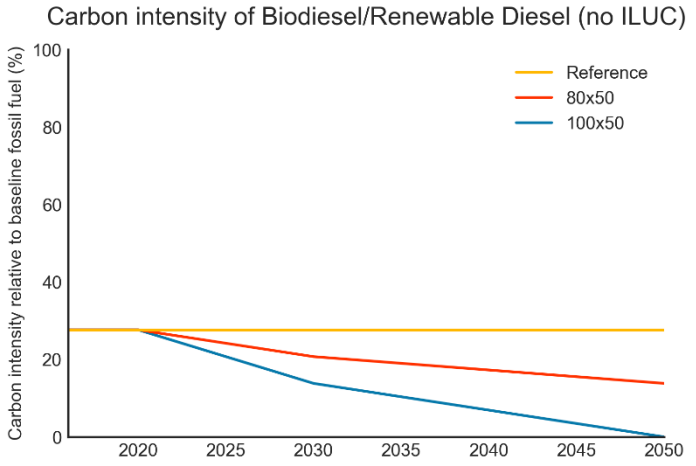


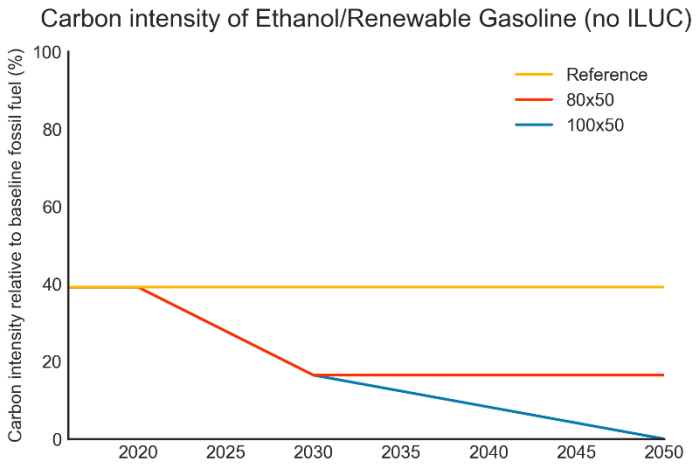
Low-carbon fuels: Biofuels
Upstream Emissions Only

Biofuels are a key measure to reduce GHG emissions from vehicles that use gasoline and diesel. We have assumed that carbon intensities are reduced through one of the following measures:

- Agricultural practices
- Process efficiency and renewable energy substitution
- Carbon capture and storage
- Advanced biofuel production

- Reference
  - Maintain current carbon intensity (CI)
- 80x50 Scenario
  - Low-carbon diesel: 50% reduction in CI by 2050
  - Low-carbon gasoline: 58% reduction in CI by 2050
- 100x50 Scenario
  - 100% reduction in CI by 2050

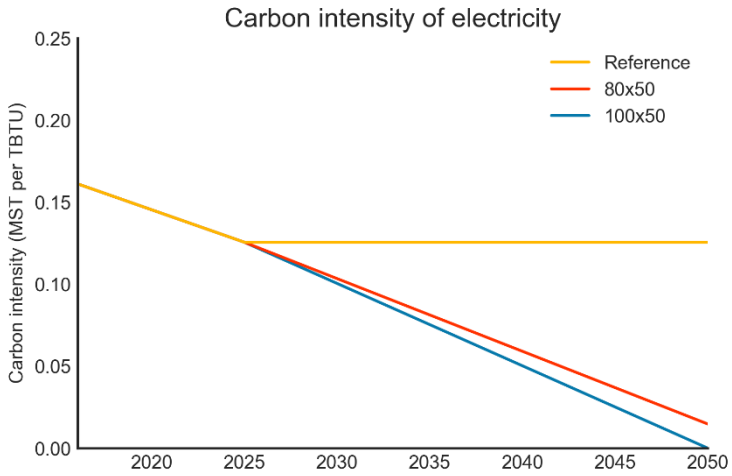




ILUC = International Land Use Change. No emissions sources outside of MN were included.

Low-carbon fuels: Electricity
Upstream Emissions Only

- As electric vehicles are more prevalent, it is important to also decarbonize the sources of electricity generation within the state
- Reference
  - Moderate reductions due to fossil retirements (20% reduction in current carbon intensity by 2025)
- 80x50 Scenario
  - 90% carbon-free electricity by 2050
- 100x50 Scenario
  - 100% carbon-free electricity by 2050

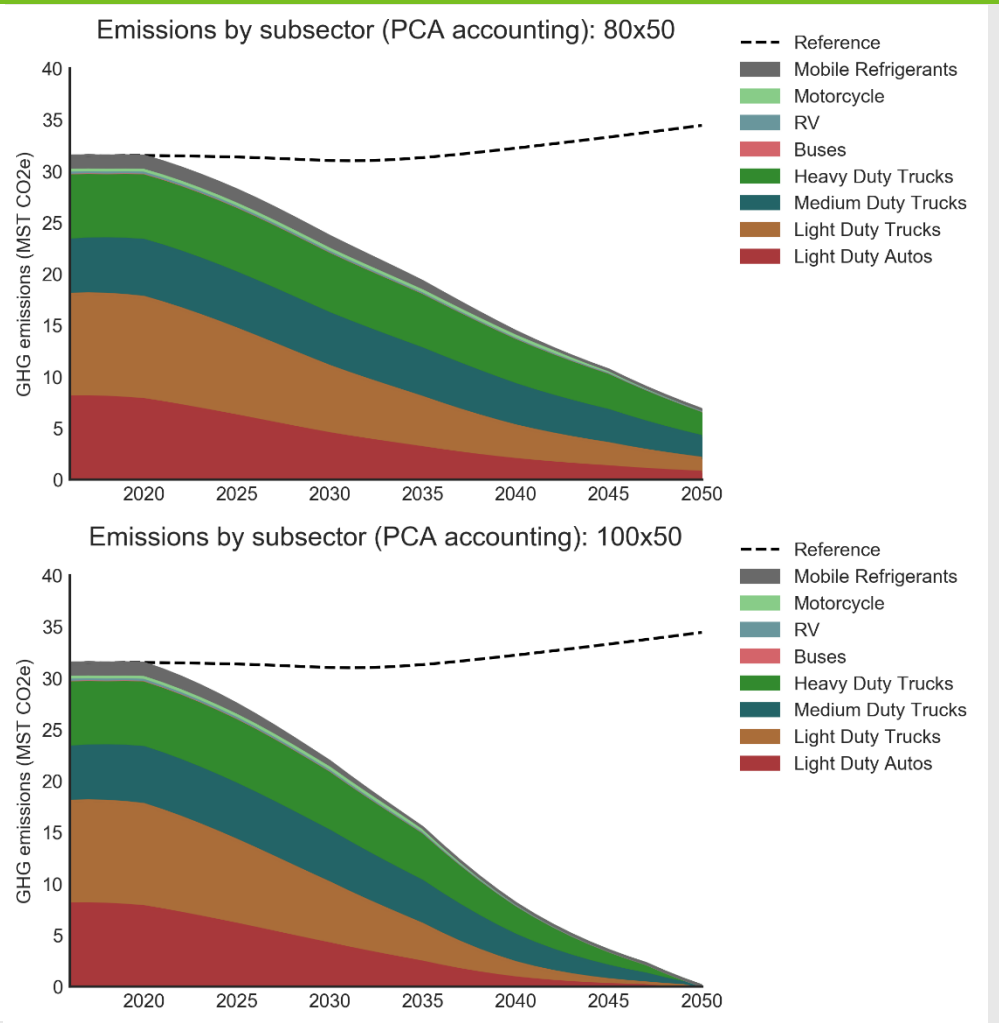


Carbon intensity assumptions
Documentation

- Current ethanol carbon intensity comes from the 2017 USDA Ethanol LCA report. “2014 Current Conditions” is used as the 2016 value.
- Current biodiesel carbon intensity comes from the Argonne National Laboratory GREET model, calculated for Midwest-produced soybean biodiesel.
- 2030 carbon intensity reduction assumption for ethanol in the 80x50 and 100x50 scenarios comes from the “2022 Building Blocks” carbon intensity in the 2017 USDA Ethanol LCA report (carbon intensity is assumed to be reduced by the ratio between the 2014 current conditions and 2022 Building Blocks numbers)
- Less data is available on the carbon intensity reduction potential for biodiesel, so simple assumptions are made on future carbon intensity
- Indirect Land Use Change is not included
- Current electricity carbon intensity is calculated from EIA and MN PCA data
- 2025 electricity carbon intensity in all three scenarios is assumed to be 22% below 2016 levels, based on projected near-term coal retirements
- 2050 carbon intensity for 80x50 scenario is calculated based on 10% natural gas generation

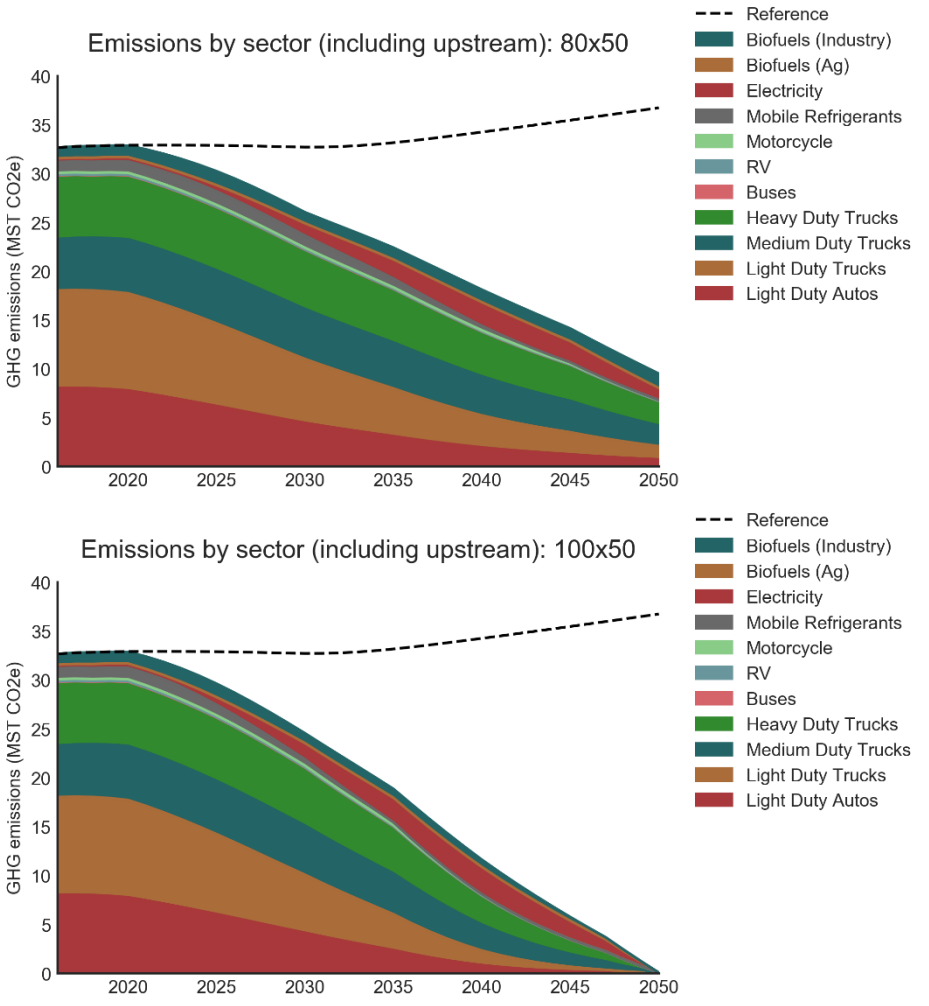
GHG Emissions by Sector
PCA Accounting

- 80x50 Scenario
  - Largest emission reductions are in light-duty vehicles and refrigerants
- 100x50 Scenario
  - Emission reductions across all sectors

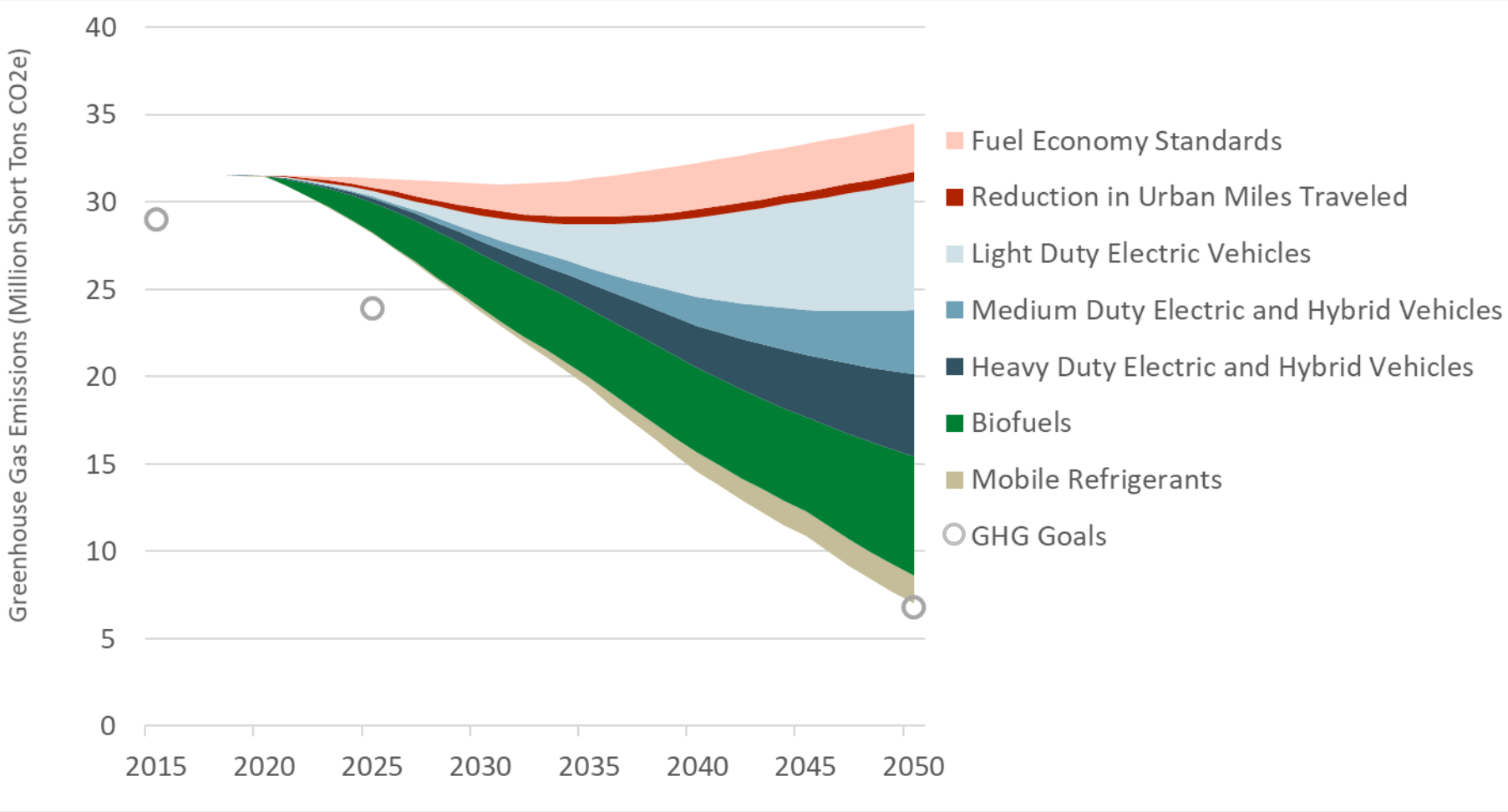


GHG Emissions by Sector
Including Upstream Emissions from Biofuels and Electricity

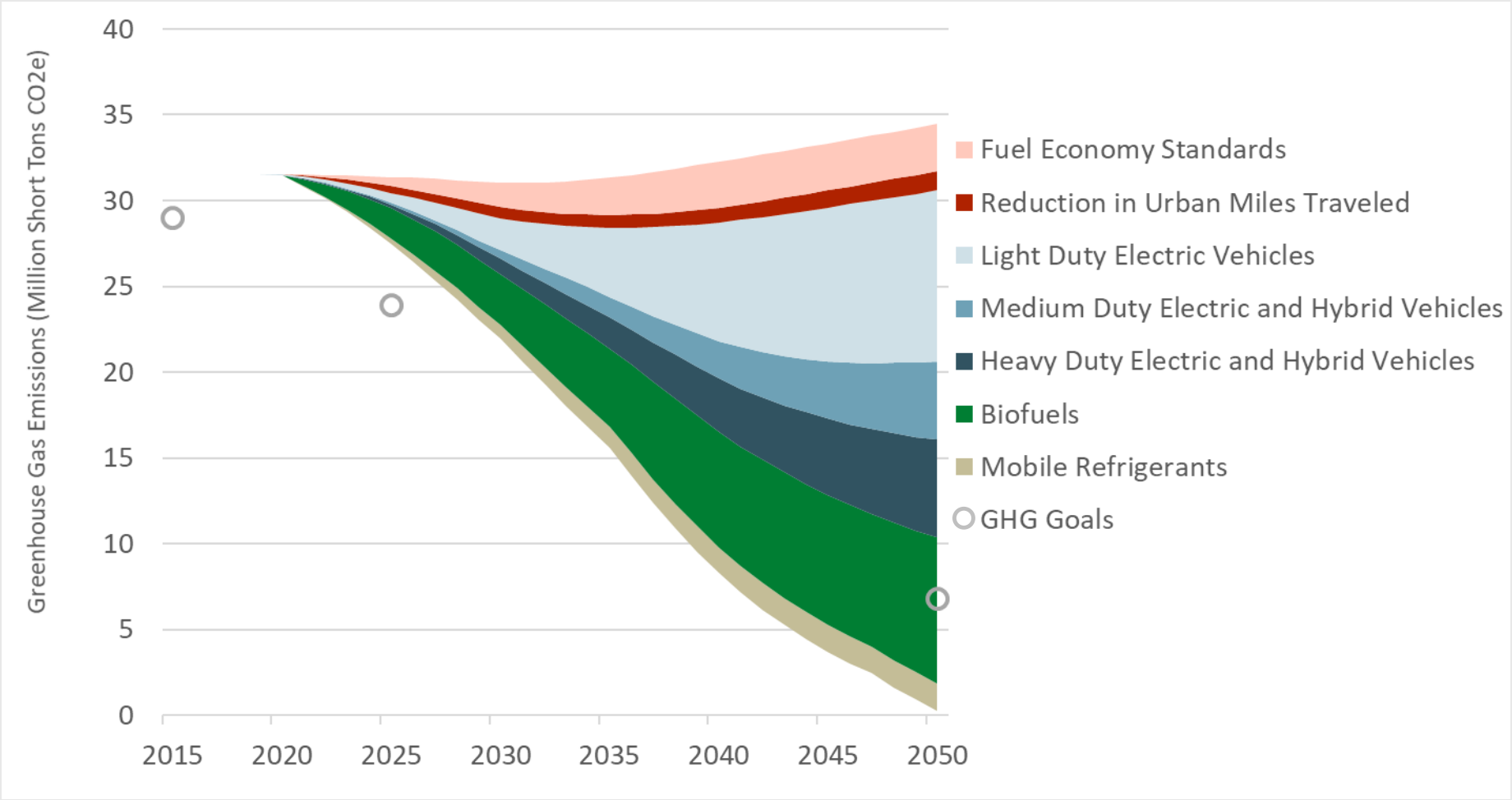
- Upstream emissions from biofuels production and electricity generation are tied to energy demands in transportation but are accounted for in other sectors of the MN economy.
- 80x50 Scenario
  - New electric vehicles and biofuel demands increases upstream emissions from electricity generation and biofuel production
- 100x50
  - Zero-carbon biofuels and electricity generation allow transportation emissions to get to 100x50



Emissions Reductions by Measure
80x50 Scenario, PCA Accounting

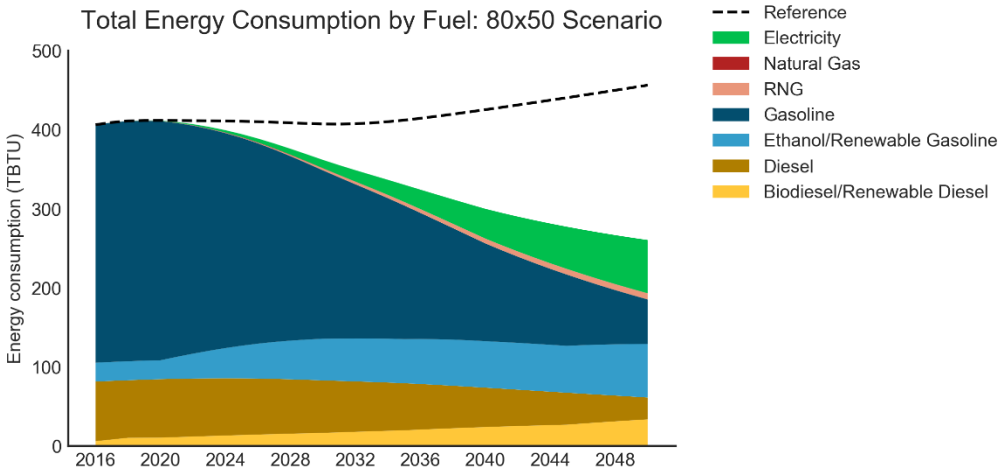


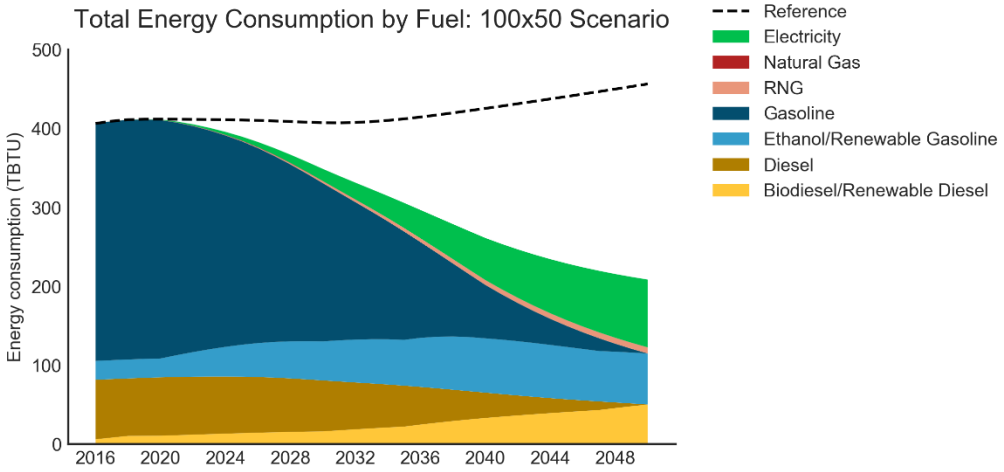
Emissions Reductions by Measure
100x50 Scenario, PCA Accounting



Total Energy Consumption by Fuel

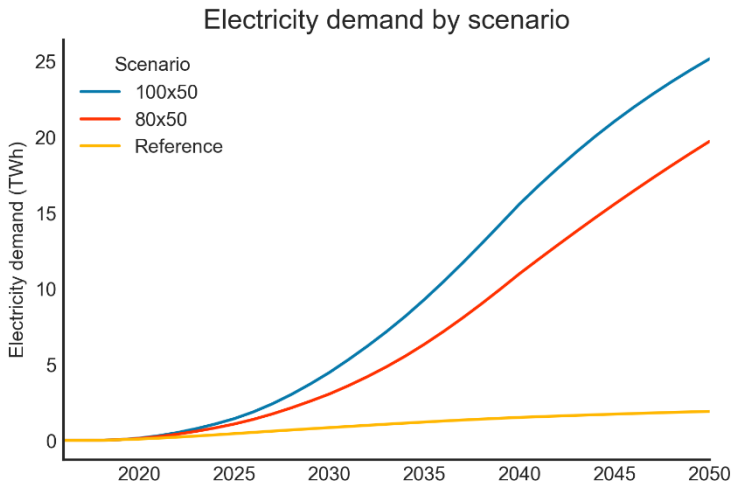
- 80x50 Scenario
  - Efficiency benefits from VMT reductions and switching to electric drive trains in EVs
  - Biofuels in gasoline and diesel increase through 2030
- 100x50 Scenario
  - Electricity demand from EVs becomes significant share of total energy consumed in surface transportation by 2050
  - All remaining liquid fuels are biofuels by 2050

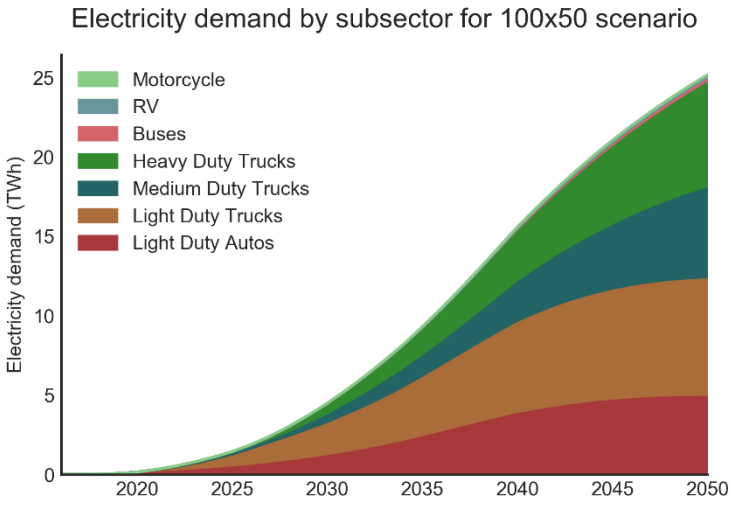




Total Electricity Demand by Sector

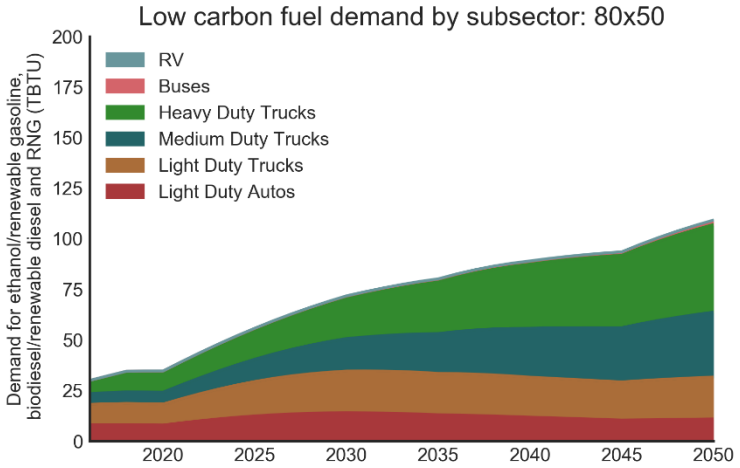
- Electricity demand from new electric vehicles ramps up significantly across all sectors in the 100x50 Scenario. In the 80x50 Scenario new electric loads are predominantly in light-duty vehicles.
- Total electricity demand in MN was about 70 TWh in 2016

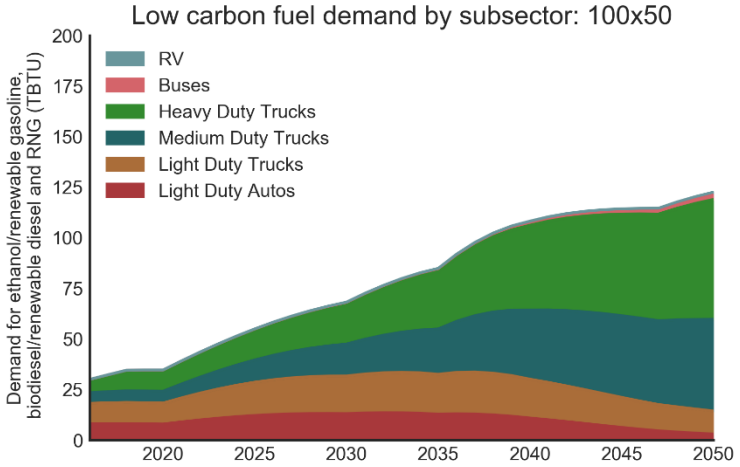




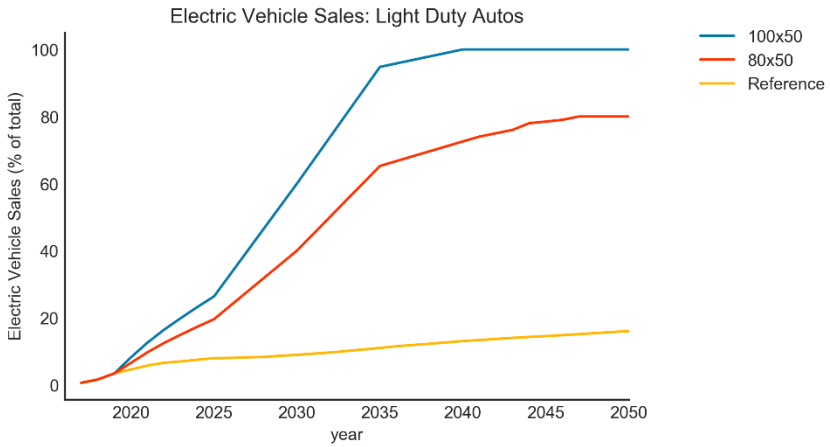
Total Low-Carbon Biofuels by Sector

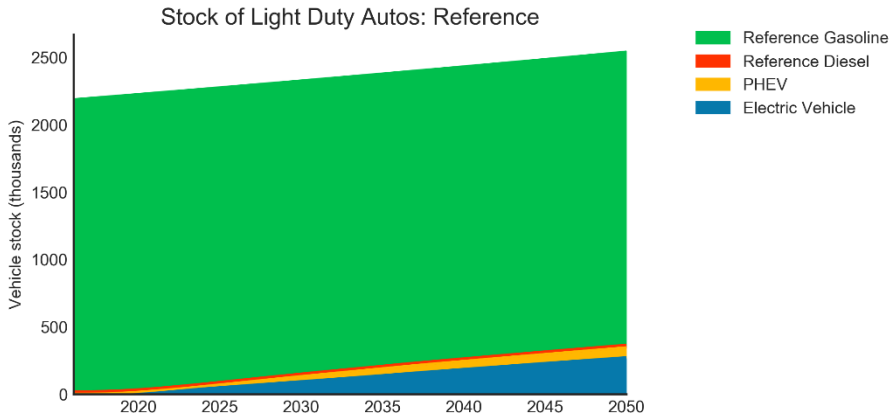
- 80x50 Scenario
  - Achieves 20% biofuels in transportation by 2030 and 60% by 2050, which increases in-state consumption of low-carbon biofuels
- 100x50 Scenario
  - Achieves 100% biofuel blend by 2050 for remaining transportation fuels

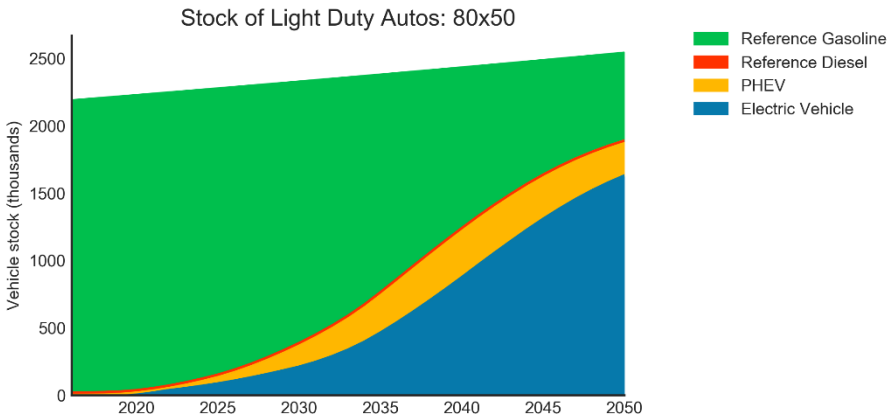


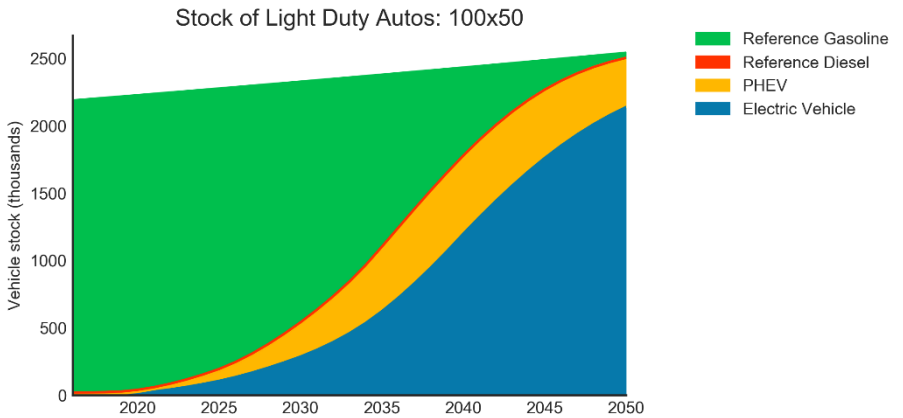


Zero Emission Vehicle Sales
Light Duty Autos

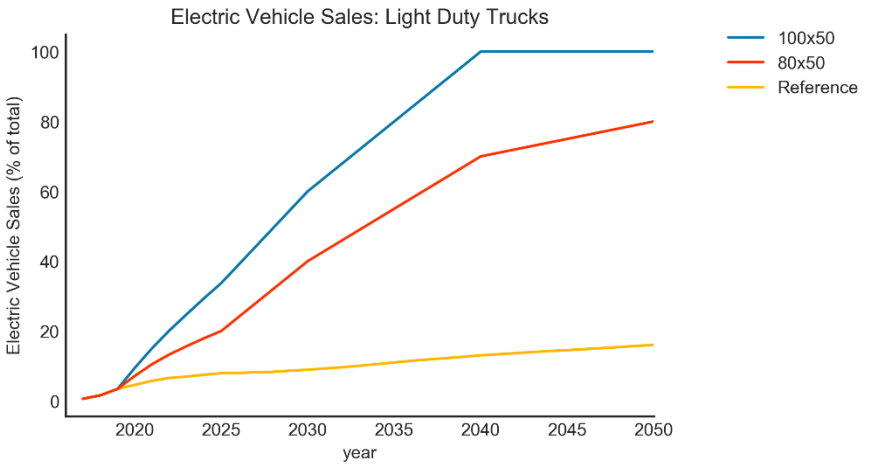


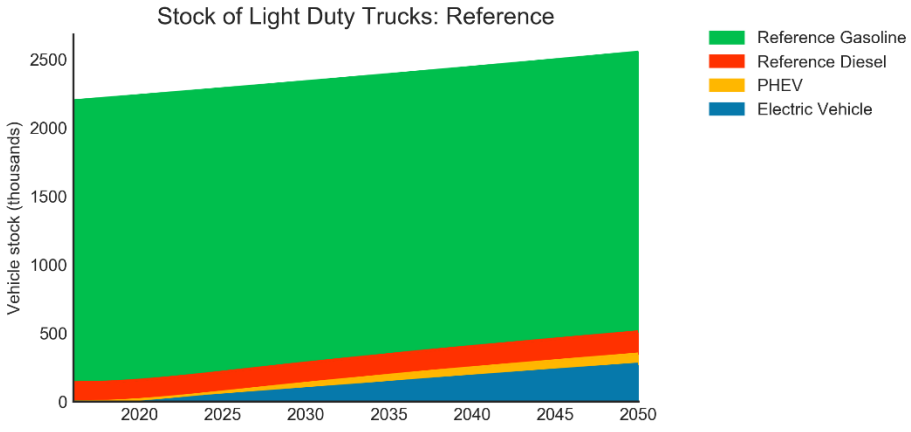


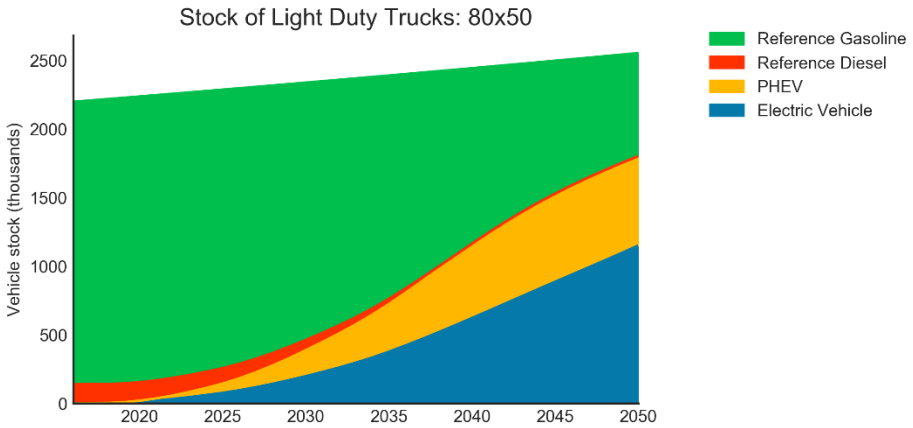


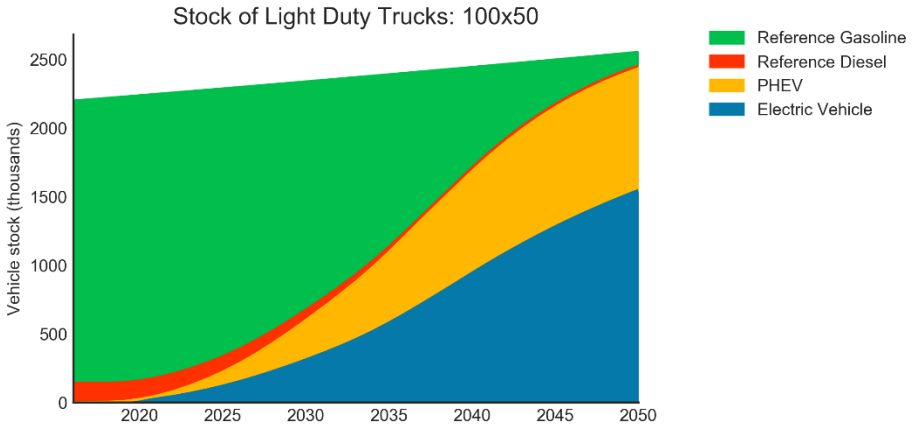


Zero Emission Vehicle Sales
Light Duty Trucks

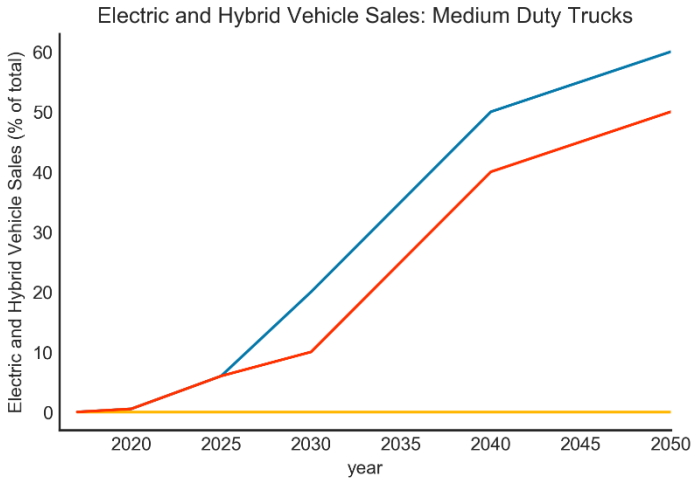


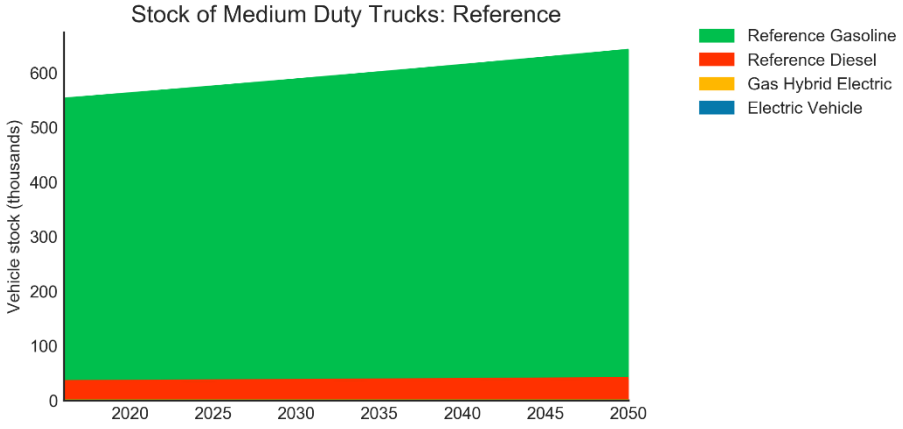


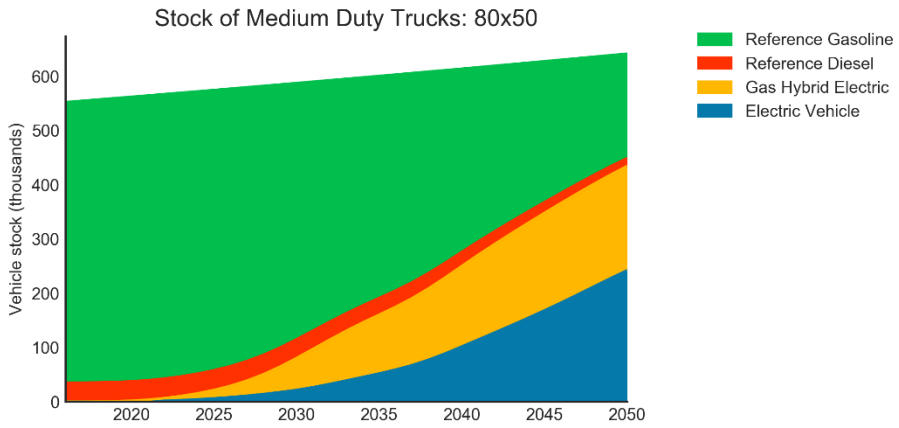


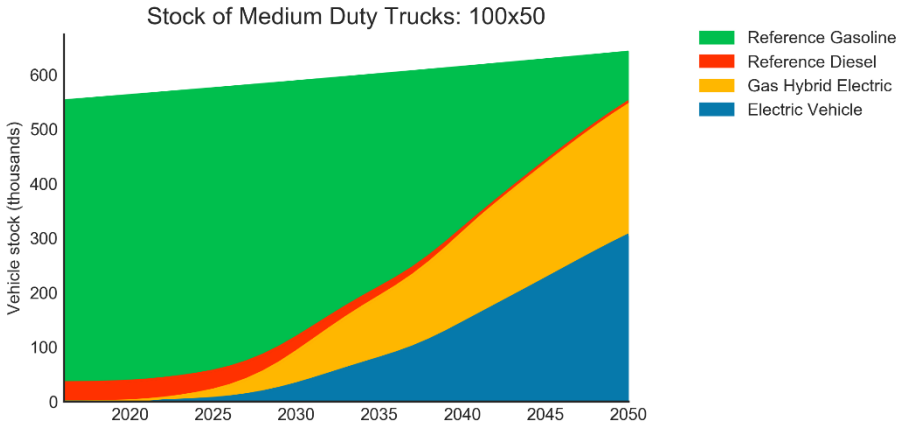


Zero Emission Vehicle Sales
Medium Duty Vehicles

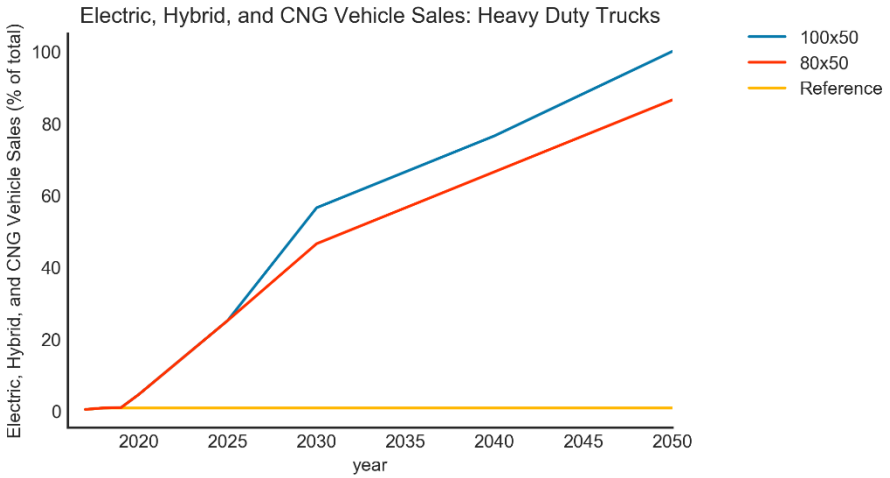


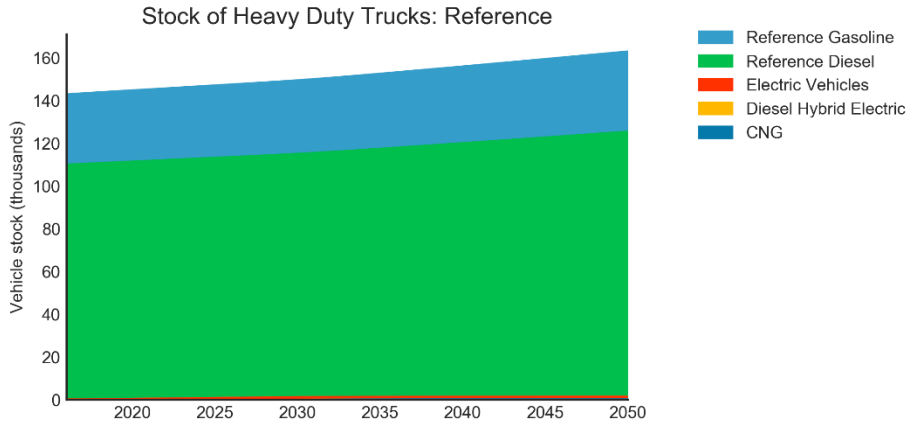


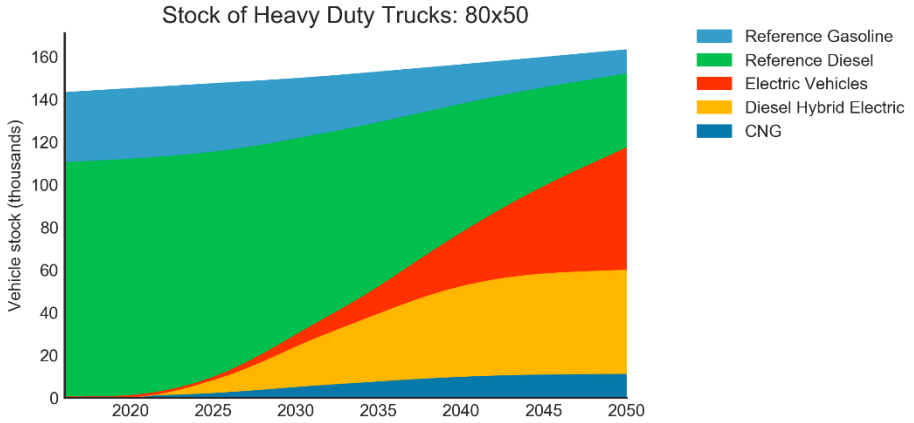


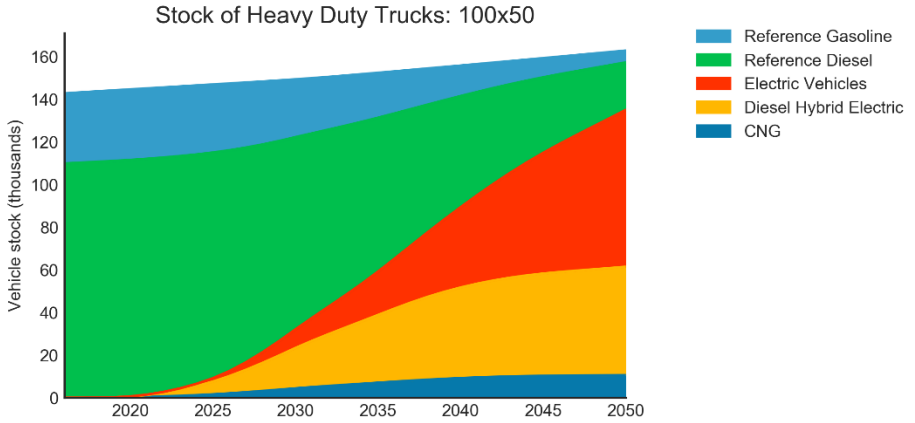


Zero Emission Vehicle Sales
Heavy Duty Vehicles

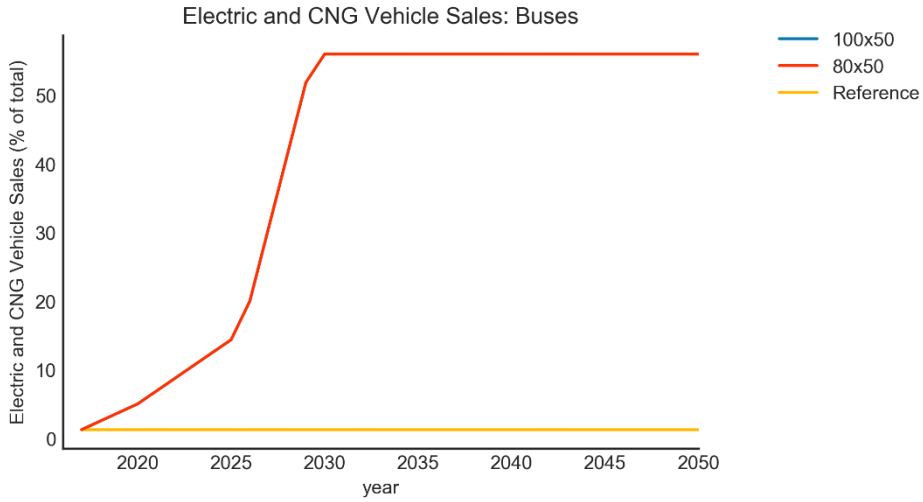


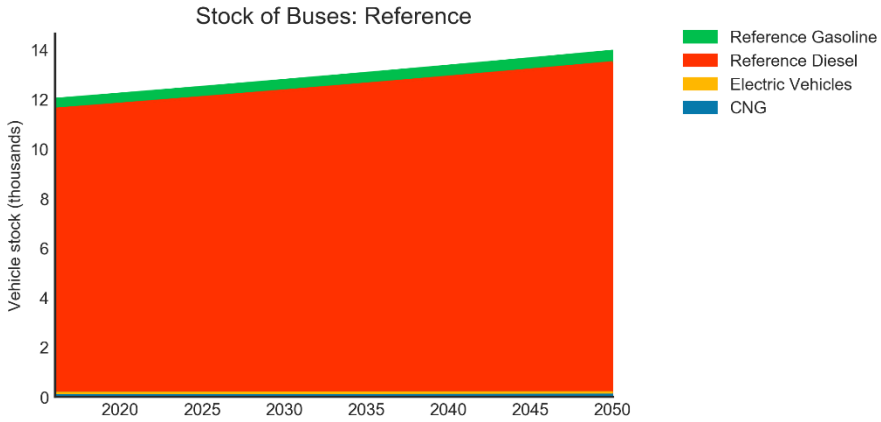


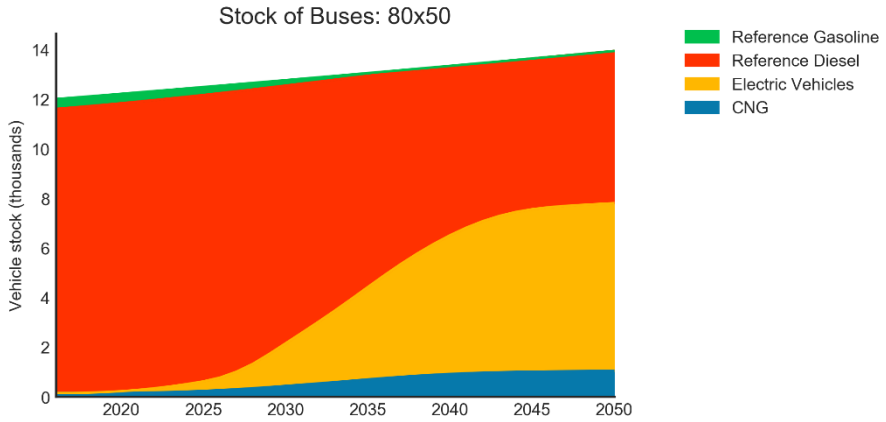


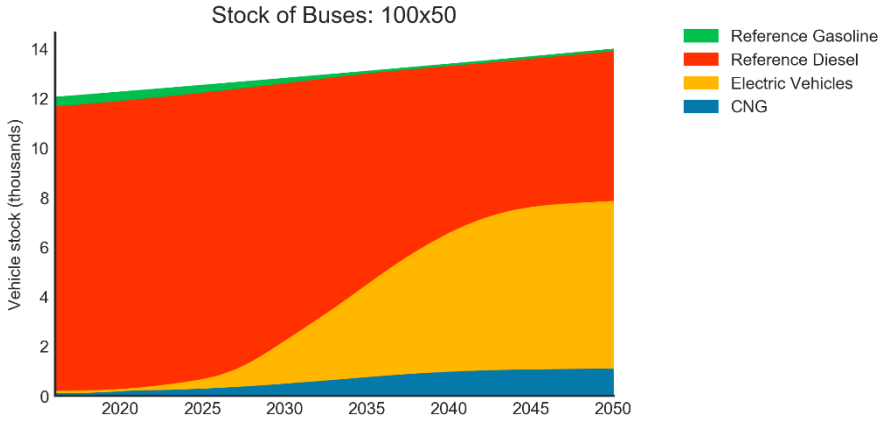


Zero Emission Vehicle Sales
Buses





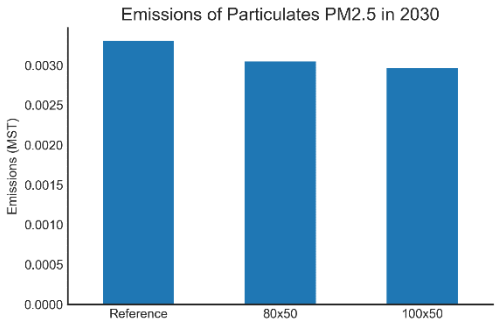
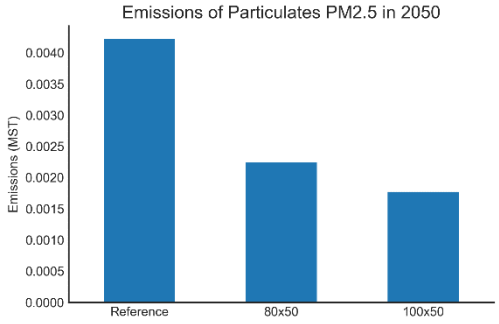
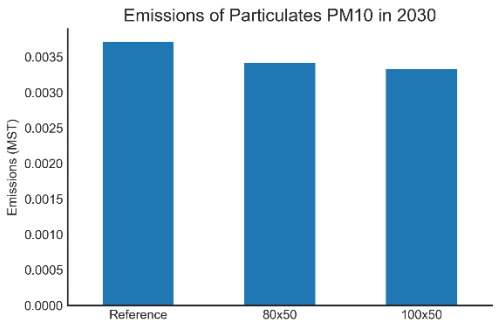
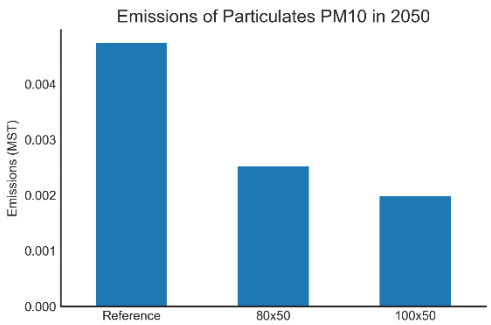




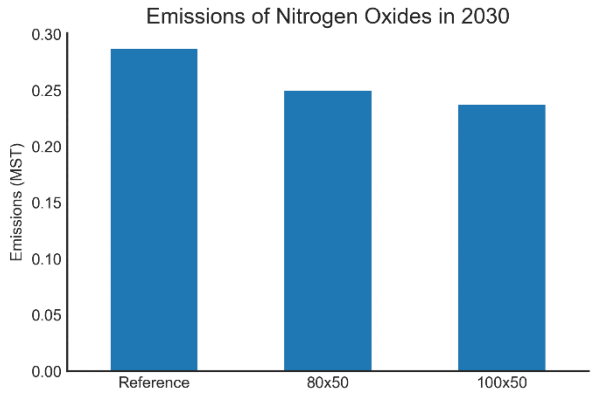
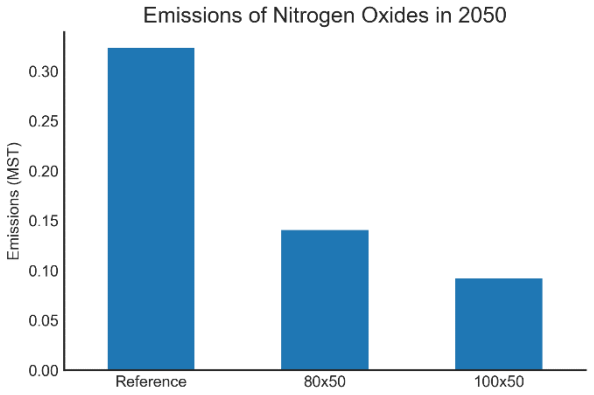
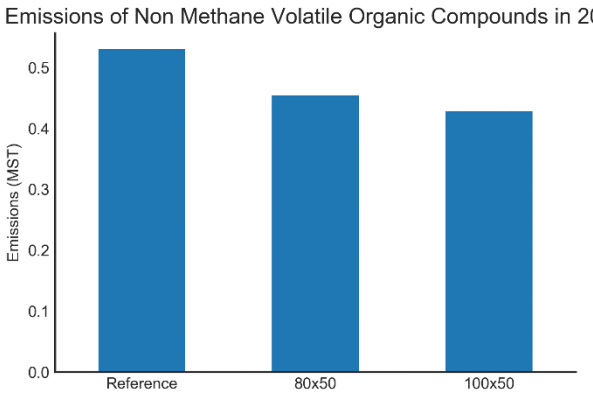
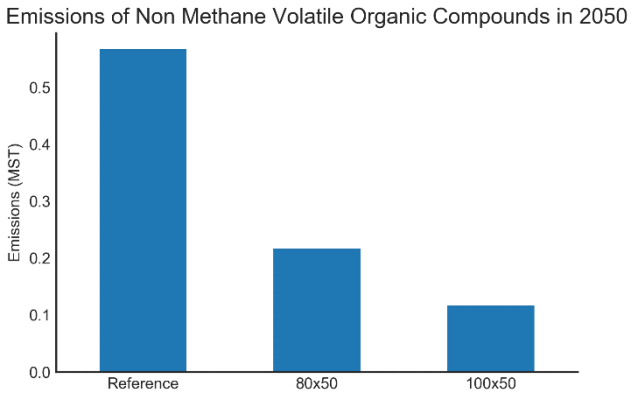
Vehicle Class Characterizations

- Vehicle class characterizations are slightly different from what is often used in studies for other jurisdictions, due to the accounting methods used in the MN PCA GHG inventory.
  - In this study, “Medium Duty Vehicles” refers to “Light Commercial Trucks,” which are all commercial trucks with four wheels (often included in the light-duty vehicles category in other studies)
  - Heavy Duty Vehicles refers to all commercial trucks with more than four wheels (this encompasses what is often considered MDVs in other studies)

Air Pollution from Surface Transportation
Statewide Emissions

	2030	2050
Particulate Matter (PM2.5)		
Particulate Matter (PM10)		

Air Pollution from Surface Transportation
Statewide Emissions

	2030	2050
Nitrogen Oxides (NO_x)		
Volatile Organic Compounds (VOCs)		

Reference Scenario Results